Climate Resilient Technologies for RICE BASED PRODUCTION SYSTEMS in Eastern India

EDITORS

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PREFACE

We believe that a book on climate-resilient technologies (CRT) for rice-based production systems is needed with a particular focus on eastern India. So, we designed the book to address every aspect of CRT starting from the basic mechanisms of climatic stress tolerance to resilient production and protection technologies, and socio-economic issues in a lucid language. We strongly believe that the abiotic stress tolerance mechanism must be linked with advanced breeding methodologies, technological innovations in rice establishment, and socio-economic policy frameworks. We hope students, researchers, scholars, investors, scientists as well as policymakers will enjoy reading this book and may gather some useful knowledge in their respective fields of work. The major aspects of climate-resilient technologies of rice-based production systems in eastern India, which are discussed in this book are improvement of rice-physiology through advanced breeding techniques; sustainable production and protection technologies pertinent to rice cultivation in eastern India; and participatory socio-economic frameworks of 'climate-resilient agriculture' (CRA) in India.

The four themes of the book are having twenty-six chapters altogether that systematically cover the approaches and techniques of CRA. The book deals with four broad themes, namely improvement technologies for the rice production system, production technologies for rice-based production system, protection technologies for rice-based production system, and social science components of CRA in eastern India. The twenty-six (26) chapters of the book are distributed among these themes. The first six chapters (chapter no. 1 to 6) are devoted to rice crop improvement technologies, with a focus on the tolerance mechanism of rice to submergence, stagnant flooding, drought, and high-temperature stresses. The advanced breeding technologies to cope with stresses are covered with a special emphasis on speed breeding and gene editing techniques.

The production technologies are covered in ten chapters (chapter no. 7 to 16), which extensively discuss the technological approaches including direct-seeded rice (DSR), weed management, water and nutrient management, crop diversification, conservation agriculture (CA), farm mechanization, post-harvest technology of rice-production systems and integrated farming systems. Three specific chapters in this theme cover organic rice cultivation, carbon management, and greenhouse gases (GHGs) emission mitigation.

The third theme on protection technologies, includes five chapters (chapter no. 17 to 21) covering the important and trending issues of climate-resilient rice protection. These are pest dynamics under changing climate, biocontrol of insect-pest, disease dynamics under changing climate, management of store grain pests, and cataloguing of rice cultivars for the major pest.

The final theme on the "social science component" of CRT in rice-based systems deals with the socio-economic impact of climate change on rice systems, social vulnerability, institutional innovation including FPOs in CRA. This theme comprising five chapters (chapter no. 22 to 26) also highlights various Government Schemes and Programmes in India and ICT (Information and communication technologies) which are farmer-centric and initiated in India to make agriculture more resilient to climate change.

We received unprecedented support from Director, ICAR-National Rice Research Institute (NRRI), Cuttack, Odisha, along with other ICAR institutes ICAR-Indian Institute of Soil Science (IISS), Bhopal; ICAR-Indian Agricultural Research Institute (IARI), New Delhi; ICAR-Central Institute of Agricultural Engineering (CIAE), Bhopal; ICAR-National Dairy Research Institute (NDRI), Karnal and number of scientists and well-wishers for developing the book. Those whom we wish to mention are Dr. T. Mohapatra, Dr. T. R. Sharma, Dr. H. Pathak, Dr. R. C. Agrawal, Dr. A. K. Patra, Dr. A. K. Nayak, Dr. G. A. K. Kumar, Dr. M. J. Baig, Dr. P. C. Rath, Dr. T. Adak, Dr. P. K. Dash, Mr. S. R. Padhy and Mr. Anubhab Das. We are indebted to all the authors from different parts of the country who have contributed in form of different chapters of this edited book.

We have directly acknowledged the sources of the diagrams and tables that have been reproduced from other sources and publications.

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FOREWORD

To feed an estimated 9 billion population by producing 65% more food in stressed climatic conditions is a huge challenge. The increasing constraints of high temperature, frequent drought and flood, and less availability of freshwater further make the task daunting. The world leader of environmental sciences and learned community felt that constraints on system-resilience, mitigation, adaptation, and food security should be addressed together not in isolation. The 'climate-resilient agriculture' (CRA) is a system-based solution to these complex problems. Site-specific technologies provide better resilience to the agricultural systems. Therefore, thrust should be given to 'technological-innovation', 'technology-refinement', 'participatory-technology-adaptation 'investment', and 'site-specific action' to 'climate-resilient agriculture to address the issues of food security, environmental sustainability, and climate change and jointly.

The climate-resilient agriculture has three pillars i.e., 'reinstate system resilience', 'sustainable food production', and 'adaptation to climate change'. It directly addresses the issue of mitigation and indirectly those through building the intrinsic system tolerance. It is a feasible approach that focuses on natural resources management, agricultural production, and climate change adaptation with location-specific flexibilities. So, the CRA takes care of producers, consumers, and investors with economic synergies. However, long-term policies, mainstreaming of the regulating framework, proper monitoring, and capacity building are necessary for promoting climate-resilient agriculture. This book provides a good coverage of the CRA approaches covering crop-improvement, -production, and -protection technologies of rice-based systems from an eastern Indian perspective. The chapters cover the important aspects of CRA including tolerance mechanisms of rice for drought, submergence, and high temperature; advanced breeding technologies for climate-resilient rice cultivars; production and protection technologies; and social aspects of CRA. These approaches are crucial and likely to draw the wide attention of students, researchers, investors, and policymakers at large to the issues of climate change.

The authors placed the local as well as national issues, technological development, challenges, and adaptation strategies of 'climate-resilient agriculture' with a comprehensive and lucid language providing field data, concept-flow charts, and existing national policy framework with examples and explanations. The book is a state-of-art documentation on the issues of resilient agriculture, sustainable food production technologies in eastern India, and climate change adaptation in agriculture. I congratulate the authors for their great efforts to bring out this timely publication.

Baramati, Maharashtra, India

(H. Pathak)
April, 2022

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CONTENTS

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Chapter 01

Tolerance mechanism of rice in submergence and stagnant flooding stress

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Abstract

In the era of global climate change, plants are more prone to different abiotic stresses which leads to multi-faceted problems resulting in severe yield penalties. Irregularities in rainfall patterns, rise in sea level, and sudden downpours result in more frequent events of flash flooding or prolonged water stagnation in crop fields than ever before. Rice being a semi-aquatic plant can tolerate this excess water stresses way better than most of the other cereals. Most rice genotypes can tolerate 2-3 days of complete submergence without any physiological or metabolic damage, but in reality, more often than not the period of stress is much longer in the field condition. Due to the broad genetic base of rice, we have few genotypes that can tolerate complete submergence for a continuous period of two weeks or more. Similarly, some genotypes can tolerate a partially submerged condition prolonging to several weeks to months without much yield penalty. Interestingly, plants adopt two distinctly different strategies to overcome these two stresses. For submergence, tolerant rice genotypes usually adopt a low-oxygen quiescence strategy and in case of prolonged stagnant flooding stress, it follows a low-oxygen escape strategy. Both these processes are majorly governed by complex regulation of ethylene mediated cascade of events controlled by several gene actions. In this compilation, we highlighted the major mechanistic differences a possible adaptive strategies that plants employ to overcome these extremely contrasting events of excess water stresses.

Keywords: Waterlogging; aerenchyma; stagnant flooding; oxidative stress; post-submergence recovery

1. Introduction

Rice is the most important food crop in the world, feeding more than 3.0 billion global populations. Nearly half of the world's population depends on rice for their dietary intake (Liu et al. 2015). As rice is cultivated throughout the world in different agro-climatic conditions, it faces several abiotic stresses during its whole life cycle. Among all the abiotic stresses, submergence is the third most devastating abiotic stress which affects rice production and productivity in lowland and flood-prone areas (Setter et al. 1998; Ismail et al. 2013; Oladosu et al. 2020). About 22 million hectares of rice cropping area is affected by flash flooding out of which almost half belongs to Eastern India (Dar et al. 2017). Submergence is a type of flooding (short-term and long-term) stress where the entire plant is fully immersed in water. The frequency and duration of rainfall are increased due to global climatic change which detrimentally affects the plant growth and development. Such irregular rainfall patterns often lead to adversities either as water deficit or flooding conditions which may create devastation in near future. Submergence significantly reduces the rate of gas diffusion in and out of the leaf surface and restricts the uptake of oxygen leading to inadequate carbohydrate metabolism (Panda et al. 2017). Inhibition of underwater photosynthesis and reduced availability of light are some of the constraints appended with floodwater-induced stress (Das et al. 2009). Due to restricted gas exchange, transpiration is also severely affected which ultimately hampers the nutrient absorption and transportation from soil (Pederson 1993, Bailey-Serres 2014). Consequently, maintaining a sufficient amount of non-structural carbohydrate content during pre- and post-submergence is important for the adequate supply of energy to perform plant metabolic processes (Bhaduri et al. 2020; Das et al. 2001).

The crops, especially rice being a semi-aquatic plant are severely affected by flooding which leads to loss of yield every year (Voesenek et al. 2015). As a consequence, it has the capacity to tolerate climatic constraints that other crops cannot (Sarkar et al. 2019). To cope with the submergence, rice takes up two different strategies i.e., quiescence or low oxygen quiescence where it exhibits very restricted stem elongation during submergence (Colmer and Voesenek, 2009). Such reduced elongation under submergence is important for plant survival as plants tend to lodge as soon as the water subsides (Vergera et al. 2014). Another one is an escape strategy or low-oxygen escape syndrome exhibited by the plants where faster inter nodal elongation occurs to come out from water (Bailey-Serres and Voesenek, 2009). Due to rapid elongation, leaf tips extend above the water level and can perform photosynthesis and gas exchange for respiration (Bailey-Serres and Voesenek 2008). The elongation process is regulated by several types of hormones but ethylene plays the most important role. Primarily biosynthesis of ethylene is activated and accumulated in plant tissues and later it regulates the synthesis of GA and ABA. For the GA-induced internodal elongation, the overall ratio of GA/ABA in the cell is necessary for the elongation process (Kande et al. 1998). Steffens et al. (2011) reported that aerenchyma formation was enhanced by ethylene. There are two important genes SK1 and SK2 are responsible for internodal elongation (Hattori et al. 2009). SK1 and SK2 introgression in deepwater rice could enhance internode growth and play a key role in the escape mechanism under submergence. This chapter deliberates the physiological, biochemical, and molecular basis of the rice plant in response to submergence stress and highlights the key mechanistic differences with stagnant flooding stress in rice.

2. Physiological and biochemical basis of submergence

2.1 Adaptation of leaf morphology and anatomy

Super-hydrophobic leaf surfaces that have a fine layer of the gas film are now identified as a key feature in several wetland plant species which facilitates underwater gas exchange during the complete submergence process (Verboven et al. 2014; Pederson and Colmer, 2012; Chakraborty et al. 2021). The uptake of CO_2 is enhanced by leaf gas film during underwater photosynthesis during the daytime, while in darkness this helps internal aeration of submersed tissues by increased O_2 uptake (Winkel et al. 2011; Pederson et al. 2009). Under O_2 shortage conditions, the leaf gas film extensively increased O_2 flux into submerged leaves. Leaf gas film delay salt entry into leaves of the submersed plant, increasing underwater photosynthesis and internal aeration in submersed saline water (Teakle et al. 2014). It controls Na^+ and Cl^- entrance so that the plants can survive under saline submerged conditions. This also helps in gas exchange in submerged plants (Colmer and Pederson 2008; Raskin and Kande 1983). The leaf trait particularly having a thin cuticle and re-oriented chloroplast can improve gas exchange thereby helping in underwater photosynthesis (Mommer et al. 2005).

2.2 Aerenchyma formation and elongation ability

The significance of aerenchyma under submergence is well recognized and studied that the exposure of seven days of complete submergence induced the formation of aerenchyma is faster in the root of tolerant FR13A than IR42 susceptible genotypes (Nishiuchi et al. 2012). The formation of aerenchyma helps in the transport of water from the well-aerated shoot to the submersed root (Jackson and Armstrong 1999) and this specialized structure is helpful to minimize O_2 loss from the root apex as well as acting as a barrier to the movement of soil-derived toxins and gas into roots (Grenway et al. 2006). The formation of aerenchyma, narrow leaves, and leaf mass/area perhaps facilitate enduring the detrimental effect of anoxia under submergence stress. Submergence tolerant rice genotypes generally exhibit limited elongation during submergence, which is important for plants' survival as the plants lodge immediately after desubmergence (Sarkar et al. 1996; Das et al. 2005). Sarkar et al. (2011) reported that plants having *SUB1* QTL do not increase height very much and found a greater survival percentage.

2.3 Pigment content of leaf and underwater photosynthesis

During submergence, the protection of chloroplast integrity is important for the survival of the plant. Under submerged conditions, the degradation of chlorophyll content and fast change in chlorophyll fluorescence were reported in susceptible genotypes. Therefore, chlorophyll fluorescence (ChlF) traits may be treated as an important criterion to select submergence tolerant rice varieties (Panda et al. 2008). During submergence, underwater photosynthesis and utilization of carbohydrate is important for plant survival which is positively correlated with plant biomass, sugar, and starch content of root and shoot (Sarkar et al. 2006)

2.4 Role of non-structural carbohydrates

Non-structural carbohydrates are essential for providing energy to the plant tissues to maintain the metabolic process during submergence and during recovery of the plant after desubmegernce (Panda et al. 2017; Sarkar 1998). Different studies have proved that the tolerance level was not associated with initial carbohydrate content before stress imposition but rather it is associated with the plants' ability to retain high carbohydrates content by slower utilization during submergence or maintain underwater photosynthesis (Sarkar et al. 2014).

2.5 Antioxidants and oxidative stress

After the flooding subsides, submerged plants get sudden exposure to the aerobic condition as a result of speedy oxygen entry in to plant causing oxidative damage by producing reactive oxygen species (Setter et al. 2010; Bailey- Serres 2011; Crawford 1992). The cellular destruction by oxidative stress and antioxidant activity has been reported in plants during submergence (Blokhina et al. 1999). This suggests that the adaptive mechanism to cope with oxidative stress and dehydration may be important to determine the degree of tolerance to complete submergence

During the hypoxia condition, the plant adapts to build up higher antioxidant activities in tolerant genotypes. It is necessary and helps to maintain the function of enzymes under hypoxia or anoxia conditions. Inhibition of CO_2 assimilation during complete submergence decreases the activity of Rubisco, leaf chlorophyll content, and stomatal conductance The decline is more prominent in susceptible than tolerant variety during submergence (Panda et al. 2013).

3. Molecular mechanism of submergence tolerance

The molecular mechanism underlying the regulation of submergence stress tolerance in rice has been developed through the functional characterization of important genes which is responsible for the acclimatization of submergence stress (Xu et al. 2006). Plants followed two different types of strategies i.e. quiescence and elongation, during submergence depending upon the nature of flooding. On the sudden occurrence of submergence, some genotypes of rice elongate their leaves to get an appropriate amount of light and oxygen required for photosynthesis. But the process of elongation consumes a large amount of energy essential for performing other phenomena, the shortage of which causes high yield reduction. To conserve the energy level some genotypes, suppress the growth until the water level recedes. The above strategy is well known as the "quiescent strategy". This strategy is mostly adopted in flash flooding, where *submergence 1A* (*SUB1A*) is responsible for the tolerance trait (Nagai et al. 2010). *SUB1B* and *SUB1C* are present at the *SUB1* locus and mostly in all the accessions of rice but *SUB1A* is limited to some *indica* and *aus* genotypes. An *indica* genotype, FR13A confers survival of 14-15 days of submergence has the major QTL *SUB1A* present in chromosome 9 was the most important trait for flash flooding response (Singh et al. 2010; Toojinda et al. 2003; Xu and Mackill 1996). However, some rice genotypes follow an escape strategy to overcome the stress. A Group of deepwater rice grows rapidly under rising water levels in flooding conditions. The reason behind it is a rapid elongation of internodes to reach above the water surface to supply oxygen to shoot meristem under anoxia conditions (Kende et al. 1998). *AP2/ERF* transcription factor responsive genes *SNORKEL1* and *SNORKEL2* (*SK1 and SK2*) are found in only deepwater rice cultivars and absent in other rice cultivars (Nagai et al. 2012; Hattori et al. 2008). Both the *SKs* genes and *SUB1A* are preliminarily regulated by the ERF (Ethylene-responsive factor) type transcription factor but have differentially regulated hormonal responses under submergence (Bailey-Serres and Voesenek 2010).

Submergence restricts the diffusion of endogenous ethylene to the surrounding water and induces accumulation in the stem. Later, it results in a reduction in ABA content due to the production of ABA degenerative enzymes (Saika et al. 2007). The decreased level of ABA-induced the production of GA in the plant which causes the internode elongation. In the case of *SUB1A,* the induction in ethylene induces the mRNA transcripts, which suppress the ethylene mediated GA production in flash flood-tolerant rice under submergence (Xu et al. 2006; Fukao and Bailey-Serres 2008). It has been also seen that an increased level of brassinosteroid reduces the production of bioactive GA due to the accumulation of *SLR1*, a *DELLA* protein that suppresses the GA responses (Schmitz et al. 2013; Fukao and Bailey-Serres 2008), which restricts the GA mediated elongation and reduce the breakdown of carbohydrates. While in the case of deepwater cultivars, the elevated level of *SK* transcript induces the production of GA in response to submergence, which triggers the internode elongation in the case of escape strategy (Fukao and Bailey-Serres, 2008). The physiological traits related to recovery from flooding are regulated by SUB1A by restricting carbohydrates breakdown and accumulating different types of amino acids under submergence and are rapidly restored the carbohydrates level during the recovery period in SUB1A dependent manner (Alpuerto et al. 2016).

SUB1A contributes to mitigating oxidative damage by upregulating the genes associated with ROS detoxification (Fukao et al. 2011). *SUB1A* is a member of the ERF-VII group of a subfamily that acts as a transcription factor that regulates the expression of hypoxia-inducible genes and survival of low oxygen stress (Xu et al. 2006; Yang et al. 2011; Papdi et al. 2015). It has been reported that the overexpression of ERF-VII genes RAP2.2, RAP2.3, and RAP2.13 play a vital role in tolerance to oxidative and osmotic stress (Papdi et al. 2015).

The identification of the LGF1 gene which regulates leaf gas film retention provides a better understanding during submergence stress. LGF1 regulates

C30 primary alcohol synthesis which is important for the gas film, epicuticular wax, and leaf hydrophobicity on submerged tissues. This trait increased 8.2-fold underwater photosynthesis and provide tolerance to submergence (Kurokaw et al. 2018). There are several submergence susceptible verities that are being improved for submergence tolerance by backcrossing and are also used for commercial purposes in different flood-prone ecologies (Dar et al. 2017; Sarkar et al. 2009).

4. Tolerance mechanism to waterlogging/ stagnant flooding stress

In case of waterlogging or stagnant flooding stress, plants generally follow a few adaptation strategies to withstand this condition- firstly, morphological and then, anatomical adjustment is involved for adventitious root formation, followed by induced aerenchyma formation, barrier for radial oxygen loss, and finally rapid elongation of plant apical cells or meristem (Hattori et al. 2009; Pedersen et al. 2009; Qi et al. 2019; Pan et al. 2021). Among these, the adventitious root formation is considered an adaptive mechanism in case of waterlogging stress (Steffens and Rasmussen 2016). Thin, hairy adventitious roots are generally formed from the internodes or at the base of the stem. These newly formed adventitious roots facilitate the exchange of gases, water, and nutrient and help to maintain growth and development under stress (Xu et al. 2006). Along with these, anatomical studies showed that newly formed roots contain a high amount of aerenchyma in the cortical portion of cells, which are also helpful in the O_2 uptake process and therefore important to maintain the essential cellular processes (Visser and Voesenek 2005). In extreme cases, if the waterlogging stress continues for several months then primary roots get died, in that cases, the newly formed adventitious roots can function as major organs of the nutrient and water uptake process. Next to this, in the case of waterlogging stress-induced lysigenous aerenchyma formation is considered an important trait for tolerance and crop survival (Drew et al. 2000; Evans 2004). It is also considered a major physiological and morphological adaptation that waterlogged plants follow to withstand stress (Armstrong 1979; Jackson and Armstrong 1999). Under normal aerobic conditions, in rice, lysigenous aerenchyma was formed constitutively in the root or different plant portions (Jackson et al. 1985). But in case of scarcity or deficiency of oxygen in the soil the aerenchyma development process was induced (Colmer et al. 2006; Shiono et al. 2011). It is a much legitimate induction, due to the scarcity of oxygen; oxygenation to the lower portions of cells is much more difficult in case of waterlogging or stagnant flooding stress. Therefore, to maintain the oxygen to the lower portions of cells like root and submerged portion of stem or sheath, aerenchyma formation in the cortical cells starts and this is the reason behind its induced formation/ development in case of waterlogging. Concurrently, cell wall thickness to the outer side of the aerenchyma also developed, which is helpful to maintain higher inner O_2 concentration and acts as a barrier to the radial oxygen loss process (Colmer 2002; Shiono et al. 2011).

Finally, a rapid elongation of internodes was also observed in case of waterlogging stress (Kuroha et al. 2018). Rapid elongation of stems or internodes helps to get plant parts out of submergence and thereby, plant parts can maintain the normal cellular functions and respiration. This is popularly known as ‘low oxygen escape syndrome’ (Bailey-Serres and Voesenek 2008; Colmer and Voesenek 2008), which is solely maintained by the accumulation of ethylene in cells, it further promotes the synthesis of gibberellic acid and elongation of internodes (Kuroha et al. 2018). In this section, we are first discussing aerenchyma and how lysigenous aerenchyma is formed under waterlogging or stagnant flooding stress, which facilitates the transport of oxygen to the submerged plant parts from the aerial parts of the plant. Then, the next section the cellular regulations and signalling processes that regulate the aerenchyma development process is discussed.

4.1 Aerenchyma – *a specialized structure and key factor for gaseous transport in underground plant parts and exchange of gases with environment*

Aerenchyma is a type of specialized cell that presents in the mid-cortex or cortex region of the root, stem, and sheath of plants, and contains enlarged gas spaces (Steffens et al. 2011). This is either formed by a normal developmental process or by the response of hypoxia (low availability of oxygen). Based on the reports of literature, aerenchyma formation occurs employing two distinct processes or mechanisms in plants - It can be lysogenetic and schizogenetic (Arber 1920; Evans 2004). In case of schizogenetic or schizogenous mode of aerenchyma formation process, the formation of aerenchyma is associated with differential cell growth and precise cell separation. This type of structure is found in the petiole of *Sagittaria lancifolia* (Raskin and Kende 1983). In reverse, in the case of the lysogenetic or lysogeneous mode of aerenchyma developmental or formation process, the overall aerenchyma formation process is associated with programmed cell death (Kawai et al. 1998; Evans, 2004). For this initially, cells die and finally, cells are removed to create gas spaces. This type of aerenchyma is commonly found in the root portions of barley, wheat, rice, and maize (Steffens et al. 2011).

The aerenchyma formation process was first identified by Sachs (Sachs, 1882). It facilitates the gaseous exchange process between submerged plant parts and the aerial portion of cells. In case of the root tissue portion, the aerenchyma development was generally started at the tip of the root and expands to the lower portion (Ranathunge et al. 2003). In general, layers of the cortex cells get removed to develop the aerenchyma or gaseous spaces. In this process, other essential portions of the stele are generally unaffected (like xylem and phloem, epidermis, hypodermis, etc.). The overall development process of aerenchyma is a multiple-step process- which involves five consecutive events or steps (Evans 2004; Nishiuchi et al. 2012). In case of the lysigenous aerenchyma developmental process, which is dominant in case of gramineous plants and the process was started with (i) Perception of hypoxia and biosynthesis of gaseous hormone ethylene (ii) Transmission of the signal to the cortex or mid-cortex portions of cell (iii) Initiation of cell death by loss of ions, losing plasma membrane integrity (iv) Increasing the activity of cell-wall hydrolytic enzymes, chromatin condensation and DNA fragmentation (v) Degradation of the cell wall and cell lysis events (Evans 2004; Nishiuchi et al. 2012).

4.2 Role of ethylene in case of stagnant flooding and aerenchyma development process

The induced development of aerenchyma started with the biological entrapment of ethylene in the lower /submerged portions of the cell. Ethylene is a gaseous phytohormone of plants that accumulate in the root cells due to the waterlogging/ flooding in soil. Its biosynthesis stimulates the programmed cell death process by activating a series of processes in the cell (Justin and Armstrong, 1991; Colmer 2003). The activity of the ACS (ACC synthase) and ACO (ACC oxidase) enzymes is important for ethylene biosynthesis and studies on this showed these enzymes are upregulated in case of a low oxygen environment. Early reports on cell signalling by Subbaiah et al. 1994 showed that due to oxygen deprivation, Ca^{2+} is released from mitochondria to the cytosol. These released Ca^{2+} ions initiate the function of different protein kinases during the aerenchyma development process. Mechanistically, elevated ethylene production in the root cells activates G-protein related/ coupled receptors, phosphoinositides, and calcium ions. Based on Colmer et al. (2006) Calrose root aerenchyma formation was increased in rice genotype when it was treated with gaseous phytohormone ethylene. Similarly, in the case of root of maize, Rajhi et al. (2011) by microarray analysis showed that ERF (ethylene response factors) is important and it was upregulated in case of waterlogging stress. Later, Yamauchi et al. (2015) showed the expression of two biosynthetic enzymes of the ethylene biosynthesis pathway- ACS1 and ACO5 expression was highly induced in case of the lysigenous aerenchyma formation process. In case of rcn1 mutants, the expression of ACS1 is reduced; therefore, it also reduces the production of ethylene and aerenchyma development under low oxygen conditions. Similar to this finding, Chakraborty et al. 2021 through a transcriptomic approach showed that the aerenchyma development process in case of *Oryza sativa indica* rice genotypes (Varshadhan) also followed the upregulation of the members ERF1, ERF3, and ACO1. This study also showed a continuously high level of ethylene, if maintained in the cell was beneficial for the aerenchyma developmental process in case of the combined effect of waterlogging and salinity stress. Reports also suggested that pretreatment with ethylene perception inhibitor (1-MCP) cut down the aerenchyma development process partially (Yamauchi et al. 2017). These all reports gave an indication that ethylene works as a switch for the induction of the aerenchyma development process in case of rice and maize under waterlogging stress.

4.3 Role of signalling molecule calcium and its associated proteins/ protein kinases for stagnant flooding

A calcium ion undoubtedly plays a fundamental role in different types of environmental stresses (Sanders et al. 1999; Verde et al. 2018). This is also similar in case of waterlogging or stagnant flooding stress. In case of waterlogging, calcium ion-mediated signalling is also important for the lysigenous aerenchyma formation process (Drew et al. 2000). Calcium acts as a secondary messenger and orchestrates the signal to activate the cascade of genes that are important in signalling process and finally important for aerenchyma development. Different types of calcium sensors are get activated at first, which are the member of CBL (CBL- Calcineurin B type protein), CML (Calmodulin [CaM] like proteins) and CDPK (Calcium dependent protein kinases) groups. Later, these factors either interact with other calcium dependent protein kinases or directly phosphorylate to activate the genes, which are involved in oxidative stress pathway. He et al. 1996 at first showed aerenchyma development process is associated with the overall cytosolic concentration. In case of plants with treated with EGTA or reuthnium red, both are involved in to reduce the cytosolic free calcium level, blocked the aerenchyma development process. Rajhi et al. (2011) showed calcium signalling genes are upregulated and CML in case of the root under waterlogged stress. Later, Yamauchi et al. (2017) reported that function of the RBOHH genes is mediated the (CDPK), that phosphorylate the target protein to get activated the aerenchyma development process and forming the superoxide radicals. Kobayshi et al. (2007) observed that function of RBOHB in *Solanum tuberosum* is dependent on the activity of CDPK4 and CDPK5. In case of *Oryza sativa* member cv. Shiokari or cv. Nipponbare function of RBOHH is initiated by the action of ethylene and CDPK5 and CDPK13. Based on the results, expression of CDPK5 and CDPK13 were found to be higher in case of cortical cells of root (Yamauchi et al. 2017).

4.4 Function of NADPH oxidases (RBOH) for production of oxidative stress compounds

Respiratory burst oxidase homolog (RBOH) is a group of mammalian NADPH oxidases (NOX), which is important for ROS generation (Chapman et al. 2019), generally converts O_2 to O_2.- and upregulated strongly at the cortical layer cells of the submerged plant parts (Rajhi et al. 2011; Yamauchi et al. 2011). It is identified in plants by the sequence similarity of gp^{91phox} subunit of NOX2 (Keller et al. 1998). Structurally, it is a plasma membrane associated protein which having six transmembrane domains (Finegold et al. 1996). Activity of this gene in cell is countered/ maintained by Metallothionein (MT) genes that act as a ROS scavenger (Wong et al. 2004). In rice, a subtotal of 9 members of RBOH is present (Wong et al. 2007). Activity of RBOHH was important for root aerenchyma formation process (Yamauchi et al. 2017). In case of stem and sheath portion of cells, induced aerenchyma formation was mediated by OsNOX4 and OsNOX9, member of RBOH or NADPH oxidase family (Chakraborty et al. 2021). Other than, these RBOHA, RBOHE and RBOHB are involved in the plant immune responses. In case of maize, A, B, C and D isoforms of RBOH is stimulated and those are important for cell death. Function of the ZmRBOH was in the cortical cells of primary roots and induces the formation of aerenchyma (Rajhi et al. 2011). Finally, superoxides can be dismuted to form H_2O_2 by superoxide dismutase. In continuation of these works, contribution of RBOH or NOX in case of development of aerenchyma was studied by using NADPH oxidase inhibitor DPI (diphenyleneiodonium) (Yamauchi et al. 2017). Results showed that application of DPI inhibited the lysigeneous aerenchyma fromation in root. These all finding indicates NADPH mediated ROS generation is essential for the formation of aerenchyma in the roots of gramineous plants.

4.5 Role of oxidative stress compounds or reactive oxygen species (ROS) in aerenchyma development process

In general, ROS production is associated with normal cellular metabolism and induced production of ROS in cells is considered as toxic and it causes damage in cells. The reactive oxygen species molecules like O_2.-, H_2O_2 can causes severe damages in cells which include lipid peroxidation of membranes; it hampers the membrane integrity and causes leakage of ions from cells (Foyer et al. 2013). However, that concept differs in case of waterlogging or stagnant flooding stress. In case of waterlogging stress, ROS production in a controlled manner is beneficial or good for the crop survival and maintaining cellular oxygenation process. It is helpful for the plant acclimation process to low oxygen conditions (Bailey-Serres and Voesenek, 2008; Sauter 2013). In case of lysigenous aerenchyma development process; ROS generation in the cortical portion of root is necessary (Rajhi et al. 2011). Generated ROS cortical portion of cells induces the oxidative stress and due to this, cells are died by apoptosis at the mid-cortex or cortex portions of stele. Finally died cells are getting removed and create gaseous spaces, which can function like aerenchyma. Therefore, it can be said that from this point of view, a controlled production of ROS is good in case of lysigenous aerenchyma formation process (Mittler, 2017). Along with this, in case of waterlogging stress another most important factor is maintaining a low level of ROS generation to the surrounding cells of aerenchyma (Yamauchi et al. 2011). To maintain this condition, plant generally maintains high activity of ROS scavenging enzymes to the surrounding cells. Based on the studies, a high activity of superoxide dismutase, catalase and peroxidase enzyme activities were found in case of tolerant genotypes, however, activity of these enzymes was suppressed in case of sensitive plant genotypes to waterlogging stress. Overall it indicates a controlled ROS production is beneficial to maintain the lysigeneous aerenchyma development process.

4.6 Function of the Metallothionein (MT) genes in case of stagnant flooding stress

Plant metallothionein (MT) is a group of small cysteine rich proteins which is known for its multipurpose function in different stresses (Coyle et al. 2002). Few members of this family can act like ROS scavenger and others are involved in the metal homeostasis process. Plant MT family members can be classified into 4 different subfamilies (family/ class 1, 2, 3 and 4). Among them, in case of waterlogging few members are involved to ROS scavenging (Wong et al. 2004; Xue et al. 2009). Based on the reports, in rice (*Oryza sativa*) MT2b (Wong et al. 2004) and cotton (*Gossypium hirsutum*) MT3a can act as ROS scavenger (Xue et al. 2009). In case of rice knockdown of MT2b promotes/ induced epidermal cell death and aerenchyma development (Steffens et al. 2011). Research progresses identified activity of these members have a direct relation with overall aerenchyma development process, based on the reports of Yamauchi et al. (2017) a downregulation of MT members is needed in the root cortex region of rice. Specificially, activity of MT1a, MT1b and MT1Lb was reduced in the root cortex region prior to aerenchyma development. Conversely, a high acitivity of this family member can block the overall ROS generation. In maize, the induced expression of MT1 in root cortex region can decrease the aerenchyma development process. Recently, Chakraborty et al. (2021) showed that a differential activity of different OsMT (MT1A, MT1B, MT2A, MT2B, MT3B and MT4A) members could decide the plant's fate under waterlogging and combined effect of saline waterlogging stress. Though this action was downregulated in cortical cells of root, but previous studies also showed activity of these family members was constantly high in the outer and inner layer of cells of stele, which maintained a balance of ROS in the other parts of stele, remained crucial to minimize the damage.

4.7 Formation of outer cell layers of cortex that acts as barrier for radial oxygen loss (ROL)

Cellular oxygen can be losses during the transportation from aerial portion to the submerged portion of cells or to the tip of root (Pedersen et al. 2020). It can be lost by lateral leakage, therefore reducing the overall supply of oxygen to the root tip portion (Armstrong 1979; Colmer 2003). To cut down the loss of overall cellular oxygen, wetland plants generally formed a barrier outside the spaces of aerenchyma (Colmer 2003). Similarly, in case of waterlogging tolerant plant, a layer of cell present outside of aerenchyma that formed a barrier and blocks the process of ROL. It is generally formed outer side of the aerenchyma cells or peripheral cells exterior to aerenchyma and few wetland members (*Hordeum marinum*) continuously maintained such barriers in the root to check the leakage of oxygen (Garthwaite et al. 2003). This barrier is made up by lignin and suberin (Kotula et al. 2009). A study with rice plants under control and deoxygenated condition showed that lignification and suberization process in the roots were induced in case of waterlogging stress (Soukup et al. 2007). Deoxygenated condition induced early development of casparian strips and deposited lignin at sclerenchyma cells and suberin in the hypodermis (Kotula et al. 2009; Ranathunge et al. 2011). Deposition of these compounds formed a barrier that checks the radial oxygen loss. Along with this, deposition of lignin and suberin is also helpful to provide the culm strength in case of rice roots, and it provides lodging tolerance, therefore, having importance in case of waterlogging stress.

5. Conclusion and future prospect

The tolerance mechanism to submergence and waterlogging stress is very complex and the overall response of plants differs due to the depth of the water and availability of oxygen to the different plant portions. In case of submergence plants generally showed a low oxygen quiescence syndrome to overcome the adversities. It is a less energy consumption process, where stored energy during submergence is later used to rejuvenate the growth and development of the plant. Conversely or oppositely in case of waterlogging stress, the tolerant plant generally used a low oxygen escape syndrome to withstand stress. From an energy use point of view, it is a high energy consumption process, where plant stem and internodes are elongated to survive under a prolonged period of excessive water stress. Research progress has identified QTL (SUB1) for submergence, which is beneficial for withstanding submergence for nearly 2 weeks (nearly 14 days) of stress. But the question still lies, what will happen with these tolerant members, if the stress persists for a longer period of time; which process or mechanism will be beneficial then for the genotypes; either low oxygen mediated quiescence syndrome or low oxygen mediated escape syndrome. Apart from this, transcriptomics and proteomics approaches also identified several candidate genes that play pivotal roles in case of submergence and waterlogging stress. However, molecular characterization through functional validation of these genes is not available in the literature. Therefore, this particular area needs further research attention.

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Chapter 02

Tolerance mechanisms of rice for drought and high-temperature stresses

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Abstract

Owing to its high water requirement for cultivation, rice production is extremely vulnerable to the threat of changing climate, particularly prolonged drought and high temperatures. Such threats emphasise the significance of abiotic stress-tollerant rice varieties with higher yield potential. The physiological and molecular mechanisms by which rice varieties cope with drought stress (DS) and high temperature stress (HS) are investigated in this chapter. It assesses rice research studies on various phenotypic traits, genetic loci, and stress response mechanisms in order to aid in the development of new breeding strategies for rice varieties with improved resilience to abiotic stresses. It's challenging to come up with novel breeding and farming procedures for climate-resilient rice cultivars. It requires a full understanding of the different morphological, biochemical, physiological, and molecular components influencing yield during drought and high temperatures, but this can be accomplished by combining genomics and molecular breeding techniques, including genetic engineering. This chapter highlights effects of abiotic stresses such as drought and high temperature on rice growth and development and also discusses the underlying tolerance mechanisms.

Keywords: drought, high temperature, climate change, rice, abiotic, rainfed

1. Introduction

Rice ranks second to maize as the most significant cereals produced and consumed globally (Awika, 2011). In terms of rice production and consumption, Asia leads the way. According to the FAO report (2016-17), average rice production by 2030 is estimated to be 5.0 x 108 tonnes, but due to rising population, this production is expected to increase to 2.0 x 109 tonnes by 2050. A critical increase in rice crop productivity is required to meet current and future global demands, particularly on less favourable rainfed lands. Climate change is anticipated to increase the frequency and intensity of extreme weather events such as severe heat stress, severe drought, and floods, posing a serious threat to agriculture, particularly in developing nations (Nguyen, 2002; Turral et al. 2011). Drought is characterised in agriculture as a period of low mean precipitation/poor rain or greater evaporation rates, resulting in reduced crop development and productivity (Rollins et al, 2013). Drought stress affects more than one-third of the world's total cultivated area. Within that area, 42 percent belongs to developed countries, 33 percent to developing countries, and 25 percent to developing countries (Rijsberman, 2006). High temperature stress (HS) is caused by a rapidly warming climate. It is typically characterised as a temperature increase above a specified threshold level for a given period of time that causes irreparable damage to plant growth and development (Khan et al, 2019). Depending on the cropping season and variety utilised, high temperatures can affect rice yields by up to 10% for every 1°C increase in temperature (Peng et al. 2004; Tenorio et al. 2013). Plant development is accelerated, limiting the period available for yield production, resulting in lower yields (Erda et al. 2005). According to Gourdji et al. (2013), roughly 16% of rice acreage will be exposed to at least five reproductive days of temperature over critical levels during the reproductive stage by 2030, rising to 27% by 2050. In order to breed for abiotic stress resistance, scientists must first understand the physiological and biochemical mechanisms of heat tolerance in rice, as well as the genes and proteins that contribute to heat tolerance and the molecular mechanisms behind the HS response (Hu et al, 2017; Janni et al, 2020). In this chapter, we summarise the molecular, biochemical, physiological, and morphological responses of rice to drought and HS, as well as progress in elucidating tolerance mechanisms in rice to drought and HS, thereby improving rice resilience to changing climate.

2. Drought and high temperature stress effects and their response mechanisms

Effects of drought (DS) and high temperature (HS) stress conditions on rice plant growth and development, as well as the accompanying response mechanisms, have been investigated in several research works. Drought and heat stress are more damaging to crop production when they occur together (70 percent) than when they occur separately (Prasad et al, 2017). Figure 1 summarises the effects of DS and HS on the growth and development of the rice plant at various stages of development. DS and HS conditions limit rice plant yield potential, rendering the plants extremely unproductive in the worst-case scenario. Drought and high temperature stresses disrupt rice morphological, physiological, biochemical, and molecular responses, resulting in significant crop losses (Figure 2). (Hu et al, 2017; Todaka et al 2017). Germination and early seedling growth have a large impact on seedling vigour. Long-term temperature elevation reduces seed germination potential, resulting in a low germination rate and seedling vigour (Fahad et al, 2017, Liu et al, 2019). The ideal temperature for rice growth at the seedling stage is 25–280°C. Heat stress (42–450°C) causes increased water loss, withered and yellow leaves, compromised seedling and root growth, and even seedling death (Liu et al, 2016; Liu et al, 2018; Kilasi et al, 2018).

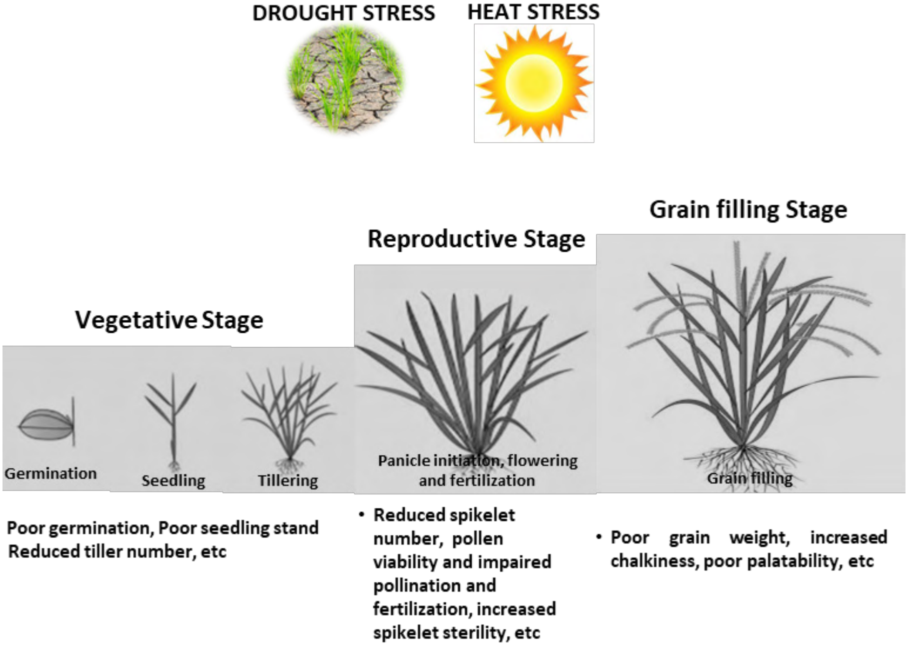

Figure 1. Growth and developmental effects of DS and HS on different growth stages of rice plant.

Drought stress causes oxidative stress by accumulating reactive oxygen species in the mitochondria and chloroplasts. In Asia's rainfed lowland (46 Mha) and upland (10 Mha) rice ecosystems, DS is the most major limitation to rice production (Pandey et al. 2007a; Pandey et al. 2007b). Important growth stages such as tillering, floret initiation, fertilisation, and grain filling are susceptible to DS during the vegetative, blooming, and terminal periods of rice cultivation (Todaka et al. 2015). According to Wang et al. (2017), drought has a considerable detrimental impact on brown and milled rice rates by affecting its quality. Terminal drought is the most destructive abiotic stress factor for rice crop production (Xangsayasane et al., 2014). Plants adapt physiologically to drought stress and dehydration, according to several studies (Basu et al. 2010; Auler et al. 2017). Drought decreases cell division and growth, leaf size, stem elongation, and root proliferation in rice crops, as well as stomatal opening and closing durations, and plant nutrient and water absorption and use (Farooq et al. 2009).

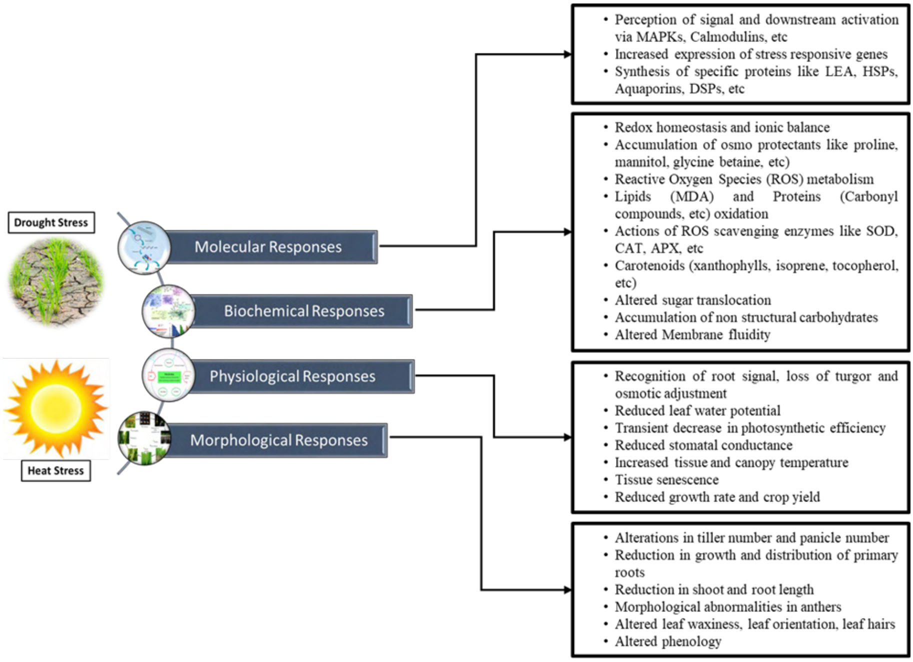

Figure 2. Various morphological, physiological, biochemical, and molecular responses in rice induced by drought and high temperature stress

3. Drought stress tolerance mechanisms

Drought-tolerant rice breeding programmes have slowed due to the complexities of drought stress in rice, as well as its strong interaction with the environment. As a result, understanding the mechanisms underlying physiological responses to drought stress and dehydration is critical. Because plants lack the ability to move and avoid drought, they have evolved several mechanisms to avoid it. Drought stress responses are influenced by plant genotypes, plant species, plant age, developmental stage, and drought severity (Ali et al. 2011; Gall et al. 2015). Drought stress resistance is mediated primarily through three mechanisms: drought resistance, drought escape, and drought avoidance. Several morphological, physiological, and biochemical traits confer drought resistance via these three mechanisms.

3.1 Three chief mechanisms of drought tolerance

3.1.1 Drought resistance

When compared to conventional water management, drought resistance refers to a crop's ability to produce its economic product with minimal loss in a water-stressed environment. Drought resistance is a complex feature influenced by the combination of morphological, physiological, and biochemical traits. Rice crops adapt to dryness by closing their stomata, rolling their leaves, improving root growth, increasing ABA production, and other processes (Price et al. 2002).

3.1.2 Drought escape

A plant's capacity to finish its life cycle before facing significant soil and plant water deficiencies is referred to as drought escape. Rapid phenological development (early flowering and maturation), developmental plasticity (change in growth phase duration depending on the level of water deprivation), and remobilization of pre-anthesis assimilates to the grain are all part of this system (Turner, 1979). Drought escape is a key technique that permits rice to produce grain despite restricted water supply in drought-prone upland areas of eastern India and Bangladesh (Bernier et al. 2008).

3.1.3 Drought tolerance

Drought avoidance refers to a plant's ability to maintain a high tissue water potential in the face of a shortage of soil moisture. Drought-resistant rice varieties are those that deal with drought by using their root systems to keep the plant watered. As a result, drought-resistant varieties reduce yield losses (Singh et al., 2012). Mechanisms that boost water intake, store it in plant cells, and reduce water loss help to escape drought. Drought-resistant rice varieties often have deep, coarse roots with strong branching and penetration capacity, a higher root to shoot ratio, leaf rolling elasticity, early stomatal closure, and high cuticular resistance, as well as a higher root to shoot ratio (Wang et al. 2006).

Drought tolerance is a multifaceted feature that is influenced by morphological, biochemical, and molecular factors. To aid in the selection or development of drought-tolerant rice varieties, a detailed understanding of the numerous mechanisms that influence rice production under water stress circumstances is essential. Drought tolerance is indicated by morphological features such turgor, leaf rolling initiation, cuticular wax, deep and coarse roots with larger xylem vessel radii and lower axial resistance to water flux. A desirable trait is the ability to maintain stomatal regulation, photosynthesis, translocation, PSII activity, chlorophyll content, and so on for an extended period of time under drought conditions. Photosynthetic ability is recognised as an important indication of plant growth because of its direct relationship to net output. Drought not only wreaks havoc on photosynthetic pigments, but it also wreaks havoc on the thylakoid membrane. The chlorophyll pigment is essential for photosynthesis, and the chlorophyll stability index is a measure of the pigments' membrane integrity that has been linked to drought tolerance. Effective ABA signalling also ensures tolerance during drought stress since ABA is a crucial component of signalling during drought stress. Furthermore, drought upregulates or downregulates a significant number of genes in rice, which enhances not only plant survival but also crop output in drought conditions.

3.2 QTLs linked to drought tolerance in rice

QTL mapping is a technique for breaking down complicated phenotypic features into their constituents and gaining insight into the genetic basis of plant phenotypes as a result of diversity and selection (Bo et al., 2015). The finding of QTLs that regulate drought stress tolerance is a critical step toward understanding the genetic basis of plant water stress tolerance and producing drought-tolerant cultivars. Because QTLs may be utilised to regulate the heritable variability of characteristics as well as numerous physiological systems that determine biomass production and partitioning, crop output can be enhanced indirectly by modifying quantitative trait loci (QTLs) (Nicholas et al., 2008). Many QTLs for drought tolerance in rice have been found for various physiological, morphological, and yield-related aspects (Table 1).

Table 1. List of QTLs identified for different physiological, morphological and yield related traits for drought tolerance in rice

Traits	No. of QTLs Identified	References
Physiological		
Cellular membrane stability	9	Tripathy et al. 2000
Leaf water relations and rolling	13	Khowaja and Price 2008
Osmotic adjustment	5	Zhang et al. 2001
Relative growth rate and specific water use	7	Kato et al. 2008
Water stress indicators, phenology and production traits	47	Babu et al. 2003
Dehydration avoidance	17	Price et al. 2002
Morphological		
Root number, thickness, length, and penetration index	28	Ali et al. 2000
Root architecture and distribution	39	Yadav et al.1997
Deep roots	6	Lou et al. 2015
Leaf area	1	Sabar et al. 2019
Coleoptile length and drought resistance index	15	HU et al. 2007
Shoot length	1	Yun et al., 2019
Physio-morphological	9	Prince et al., 2015
Yield and yield related traits		
1000-grain weight	21	Wang et al. 2014

Seed fertility, spikelet per panicle and grain yield	5	Wang et al. 2014
Panicle number /plant	14	Wang et al. 2014
Plant production	24	Prince et al. 2015
Filled grain number per panicle	23	Wang et al. 2014
Grain yield	4	Saikumar et al. 2014
Grain yield	7	Singh et al. 2016
Grain yield	2	Shamsudin el al. 2016
Grain yield	2	Cetolos et al. 2017
Grain yield	1	Sandhu et al. 2018

3.3 Genes involved in imparting drought tolerance in rice

In rice, under drought stress, several distinct types of genes are differently expressed, with roughly 5000 upregulated and 6000 downregulated genes (Bin Rahman and Zhang, 2016; Joshi et al, 2016). Some of the genes and functions connected to rice drought resistance are included in Table 2. Their expression affects the bulk of rice's biochemical, physiological, and molecular pathways during drought stress (Dash et al, 2018; Gupta et al, 2020).

Table 2. List of genes known to impart drought tolerance in rice

Gene	**Gene function**	**Phenotype**	**References**
Genes encoding osmolyte synthesis and ROS scavenging enzymes			
P5CS	Proline synthesis	Resistance to water and salinity stress	Su et al. 2004
OsGS1	High levels of proline	Drought tolerance	James et al. 2018
OsTPS1	Trehalose synthesis	seedling stage tolerance to drought, cold, and salinity	Li et al. 2011
PPO	Protoporphyrinogen oxidase	Decrease in oxidative stress and increase drought tolerance	Phung et al. 2011
OsOAT	Digestion of amino acids	Increase in drought tolerance	You et al. 2012
OsSRO1c	Scavenging of ROS	Tolerance to oxidative stress	You et al. 2013

ADC	Arginine decarboxylase	Reduction in chlorophyll loss under water deficiency	Capell et al. 1998
ADC	Polyamine synthesis	Improved drought tolerance by producing higher levels of putrescine and spermine synthesis.	Capell et al. 2004
Genes encoding LEA proteins			
OsLEA3-2	LEA protein gene	Drought tolerance and enhance grains/panicle	Duan and Cai, 2012
OsLEA3-1	LEA protein gene	Drought tolerance for grain yield	Xiao et al. 2007
HVA1	LEA protein gene	Improved drought, salinity tolerance.	Xu et al. 1996
Genes encoding TFs			
DREB2	Transcription factor	Enhanced grain yield over drought	Bihani et al. 2011
OsDREB1	Transcription factor	Tolerance to water deficient, low-temperature and high-salt stresses	Ito et al. 2006
OsbZIP72	Transcription factor	Drought tolerance & sensitivity to ABA	Lu et al. 2009
Other regulatory genes			
JERF1	Jasmonate as well as ethylene responsive factor 1	Drought tolerance	Zhang et al. 2010
OsARD4	Drought adoptive traits	Tolerance to drought	Ramanathan et al. 2018
DRO1	Root related gene	Drought tolerance	Li et al. 2017
SaVHAc1	Shoot and root growth	Tolerance to drought	Biradar et al. 2018
OsSDIR1	E3 ubiquitin ligase	Stomata regulation under drought stress	Gao et al. 2011

OsCOIN	RING finger protein	Drought, Cold, and salt tolerance	Liu et al. 2007
OsiSAP8	Stress/zinc finger protein	Improved tolerance to drought, cold and salinity stress	Kanneganti et al. 2008

4. High temperature stress tolerance mechanisms

Rice is particularly susceptible to heat stress throughout the flowering and post-flowering periods. In India, China, and Japan, short episodes of heat stress during flowering have resulted in severe production reductions. Heat stress reduces spikelet fertility irreversibly during anthesis, primarily by influencing physiological processes such anther dehiscence, pollination, and early fertilisation events. Heat escape (time of day of blossoming, particularly early morning flowering), heat avoidance through transpiration cooling, and heat tolerance through resilient reproductive systems are the three methods that plants adopt to decrease heat stress damage (Jagadish et al. 2010). Rice has been revealed to have significant genotypic variation in heat stress-induced spikelet sterility. Tolerance activities such as ion transporters, LEA proteins, signalling cascade factors, osmolytes, antioxidant defence, and transcriptional regulation are required to offset the effects of stress at the cellular level (Rodrguez et al. 2005).

4.1 Adaptation mechanisms

4.1.1 Morphological adaptations

Heat stress can be significantly reduced by modifying plant architecture. Cultivars with covered panicles, for example, are more resistant to high temperatures because they reduce anther evaporation, which reduces spikelet sterility. A decrease in evaporation rate causes pollen swelling, which is a crucial process of anther dehiscence (Shah et al. 2011). Furthermore, by utilising the avoidance strategy, genotypes with early-morning blooms have superior heat tolerance (Ishimaru et al. 2015; Bheemanahalli et al. 2017). As a result, rice genetic variability for heat tolerance can be employed as a germplasm screening criterion (Ishimaru et al. 2015).

4.1.2 Physiological adaptations

The rate of photosynthetic activity, hormone levels, membrane stability, respiration, primary and secondary metabolites, and other processes have all been found to be considerably reduced due to temperature stress (Wahid et al. 2007; Bakhtavar et al. 2015; Ahmad et al. 2016; Waqas et al. 2017). Plant survival is more dependent on leaf position, transpirational cooling, and changes in membrane lipid components when responding to a sudden heat shock (Rodriguez et al. 2005). A range of ionic and osmotic processes trigger stress-related signals, which aid in the repair of damaged cellular proteins and membranes (Vinocur and

Altman 2005). Plant genetics for high-temperature competition is unquestionably complicated. Plant growth and yield are influenced by the photosynthetic rate, which is one of the most heat sensitive physiological processes. Rice's high photosynthetic rate at heading is linked to its heat tolerance (Cao et al. 2003). A wild relative of Oryza sativa, Oryza meridionalis Ng., has a high photosynthetic rate, elongated leaves, and high amounts of heat-tolerant proteins Hsp70, Hsp90, and Cpn60 (Scafaro et al. 2010).

4.2 QTLs linked to high temperature stress tolerance in rice

Finding heat-resistance genes or quantitative trait loci (QTL) and employing them in thermotolerance breeding is a pressing task for breeders because there are few agronomic management and conventional breeding strategies for thermotolerance. Many QTL responsible for thermotolerance have been identified and validated during the seedling, booting, flowering, and grain filling developmental stages (Table 3).

4.3 Genes involved in imparting high temperature stress tolerance in rice

At various stages of cereal crop development, heat tolerance is a complicated trait regulated by several genes (Maestri et al. 2002). It behaves similarly to polygenic characteristics in rice during the flowering stage, making genetic research and breeding programmes challenging (Zhang et al. 2009). Plants usually respond to such challenges by coordinating the expression of many genes in various pathways (Vinocur and Altman 2005). Stress can cause the expression of 73 genes, 58 of which are new, according to the microarray assay (Rabbani et al. 2003). The rice genes that confer heat tolerance are listed in Table 4.

Table 3. List of QTLs identified for high temperature stress tolerance in rice

QTL	Trait	Chromosome	References
OsHTAS	Stomatal closure	9	Liu et al. 2016
RLHT5.1	Root length	5	Kilasi et al. 2018
qHTB1-1	Spikelet fertility	1	Li et al. 2018
qHTB3-3	Seed setting	3	Ye et al. 2012
Apq1	Grain filling	7	Takehara et al. 2018
TT1	Seedling stage thermotolerance	3	Li et al. 2015
SLG1	Seedling and reproductive stage thermotolerance	12	Xu et al. 2020

Table 4. List of genes which impart high temperature stress tolerance in rice

Gene	Gene function	Phenotype	References
ERECTA	Receptor like kinase	thermotolerance	Shen et al. 2015
OsIF	Involved in cellular level tolerance machinery	Increased photosynthesis and chlorophyll a fuorescence	Soda et al. 2018
OsbZIP46CA1	bZIP transcription factor	Improved thermo and drought tolerance	Chang et al. 2017
SAPK6	Protein kinase	Thermotolerance	Chang et al. 2017

5. Omics approaches in understanding abiotic stress tolerance in rice

The science of analysing the functions and interactions of biological information in distinct life clusters is known as omics. Genes (genomics and epigenomics), proteins (proteomics), transcripts (transcriptomics), metabolites (metabolomics), interactions (interactomics), and phenotype (phenomics) are all being explored (Langridge and Fleury, 2011). Approaches to genomics are mutually dependent and overlap. Integrating the data obtained from omics techniques is crucial for reaching a conclusion and comprehending significant cell response-cascades that differ in tolerant and sensitive rice varieties during that specific abiotic stress.

Genomic studies can provide a comprehensive picture of the most dominant responsive genes in tolerant varieties. Transcriptomics has revealed complex RNA expression networks that play an important role in the functioning of tolerant varieties under stress conditions. The discovery of the major proteins involved in rice plant defence systems can be accomplished using a key approach known as proteomics. Metabolomics reveals critical secondary metabolites of tolerant varieties for dealing with abiotic stress. Phenomics research assists breeders in bridging the gap between phenotypic traits and genomic data. Bioinformatics tools integrate all data obtained from "omics" sciences, resulting in the accumulation of comprehensive knowledge about abiotic stress tolerance mechanisms in rice.

6. Conclusion and future research perspectives

Drought and high temperatures, as reported in many works, cause major yield reduction in rice. Such risks underscore the need for novel climate-resilient rice cultivars that can increase crop output while also surviving abiotic pressures. Understanding the multi-mechanism responses in rice plants to drought and high temperatures is crucial for researchers attempting to improve rice's tolerance to these stresses. Several investigations have found that certain rice cultivars have molecular and physiological properties that allow plants to tolerate drought and extreme temperatures. As donor parents, these rice germplasms could be exploited to generate climate-resilient rice cultivars.

Exploring the genetic variability of rice germplasms by making genetic and phenotypic data publicly accessible considerably boosts their utility in breeding research. Leaf size, which correlates with panicle number, and root plasticity are two phenotypic features that have been identified to assist rice plants in becoming more tolerant to abiotic stresses through selection criteria for tolerance to these stresses. Furthermore, because temperature fluctuations initially affect the physiological and morphological adaptations of leaves, the links between photosynthetic, stay-green, and yield features need to be studied further. Because of its potential for avoiding high-day and high-night temperatures, the early morning flowering (EMF) trait or QTL demonstrated by O. glaberrima should be explored in rice germplasms. In addition to molecular marker technologies, the most recent breakthroughs in systems biology, such as OMICs techniques, should be applied to clarify the molecular mechanisms of genetic loci identified through QTL mapping and GWAS for more complete breeding strategies.

Furthermore, as metabolite accumulation is a common response in water-stressed plants, profiling of transcriptional factors in rice is critical. Chemicals that distinguish between tolerant and sensitive varieties can be used as biomarkers to screen germplasm materials for both stresses. Sucrose accumulation in the anthers of the ‘N22’ rice variety, for example, has been reported as a significant response to both high temperature and drought stresses. Transcriptomic analyses revealed that plants like tobacco, Arabidopsis, and wheat have similar gene expression regulations in response to both high temperature and drought stress.

Developing climate-resilient rice cultivars and component cultivation practises is a tough endeavour that involves a complete understanding of the different morphological, biochemical, physiological, and molecular traits that influence yield under drought and high temperatures. It is, however, achievable through the use of synergistic and complementary methodologies in molecular and genomics breeding and genetic engineering. The integration of various breeding approaches such as genomics, transcriptomics, metabolomics, and proteomics should be investigated in order to develop novel climate-ready crops, including rice, the main staple of populations in underdeveloped and developing countries. Furthermore, concurrent assessments of physiological, molecular, and biochemical consequences of combined high temperature and drought stress must be undertaken in well-planned field and growth chamber setups to increase knowledge and understanding of stress response mechanisms and underlying genetic features.

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Chapter 03

Current Status of Engineering C_4 Photosynthesis in Rice

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Abstract:

Enhancing photosynthesis is considered as an approach for increasing crop yield and productivity at a level to feed the ever-increasing world population. Engineering rice for establishing C_4 photosynthesis has been a promising approach and demand high attention for creating a structure that can fix CO_2 at lowest compensation point. This efficient CO_2 uptake mechanism is concurrently related to enhancing photosynthesis and yields. A high impact question that remains to be elucidated is whether implanting C_4 like structure in C_3 rice leaf could improve photosynthesis without altering the C_3 metabolism. This chapter summarizes the answer to many questions such as how long path of evolutionary changes lead to the development of C_3, C_2, and C_4 characters, whether engineering C_2 would be more efficient than implanting C_4 character in C_3 rice or why C_4 crops are more superior than C_3 and what anatomical and biochemical changes are needed to develop C_4- like C_3 plants. This chapter also highlights the significant progress in C_4 engineering in model crop such as rice and lastly the role of genome editing for enhancing photosynthesis and yields.

Key words: C_3 plants, C_4 photosynthesis, C_2 cycle, Rice, Genetic engineering, Transgenic rice, Genome editing

1. Introduction

Photosynthesis, a light driven process, alters carbon dioxide and water into energy rich sugars to support the plant growth and development (Johnson 2016). C_3 photosynthesis is found in eukaryotes and cyanobacteria, that dominates 75% of net terrestrial productivity. Approximately, 90% of food consumed by us is the product of C_3 photosynthesis. Although net primary productivity is dominated by C_3 photosynthesis, it has some limitations. Ribulose bisphosphate carboxylase oxygenase (RUBISCO) performs dual function in presence of high CO_2 and O_2 concentration. In high O_2 rich air, RUBISCO generates phosphoglycolate (2-PG), a 2-carbon molecule, which can be poisonous at high concentration. However, plant has evolved a mechanism to use this carbon skeleton of 2-PG for the regeneration of RUBP and release of CO_2 and ammonia using the energy derived from ATP and NADPH, a process called photorespiration (Eisenhut et al. 2019). High temperature favours the photorespiratory process, which limit photosynthesis by 30-50% (Ehleringer et al. 1991). During evolution of oxygenic photosynthesis, as atmosphere was limited in O_2 and rich in CO_2, RUBISCO performed carboxylation instead of oxygenase activity. Gradually, as the oxygen level increased and CO_2 level declined, productivity was affected. Low CO_2 levels in recent geographical time has substantially inhibited the photosynthesis rate in C_3 plants by photorespiration in dry and hot environment. This issue could be addressed on the evolution of some plants that have evolved a different kind of mechanism to concentrate CO_2 in the vicinity of Rubisco in bundle sheath cell (BSC), called C_4 photosynthesis (Sage and Sage 2004). A specialized anatomy, called Kranz anatomy with distinct mesophyll and bundle sheath cells (Hatch 1988) is required for proper functioning of C_4 photosynthesis. The expansion of the C_4 photosynthesis needs lots of anatomical and biochemical modification, which include expression of multiple genes, large transformation in spatial allocation of organelles and proteins, alteration of cell size and structure. High vein density is the characteristic feature of C_4 leaf. C_4 photosynthesis is a multifaceted trait that deliberates higher productivity under warm and dry conditions. C_4 plants are photosynthetically more productive and effective than C_3 plants above 30°C. In hot climates, the superior photosynthetic efficacy of C_4 plants facilitates better nitrogen-use efficiency as compared to C_3 plants. C_4 plants also have developed advanced system for water use due to the partly closed stomata that maintain concentration gradient for CO_2 and higher radiation use efficiency of C_4 photosynthesis at high light intensity. At present atmospheric CO_2 concentration of 380ppm, the efficiency of solar energy conversion to biomass is 6% in C_4 photosynthesis, whereas in case of C_3, it is only 4.6% at 30°C (Zhu et al. 2008).

2. Evolution of C_4 plants

C_4 photosynthesis independently evolved 45 times in 19 families of higher plants, and therefore is considered as a remarkable phenomenon of convergent evolution. It is most likely found in grasses followed by sedges and dicots of tropical, subtropical and warm-temperate zones. Probably, C_4 grasses evolved about 30 million years ago (early Oligocene) while C_4 dicots arose not more than 20 million years ago (Sage and Sage 2004). Despite occurring in just 3% of all plant species, C_4 photosynthesis accounts for 23% of terrestrial NPP (net primary productivity) (Sage 1999). About 40% land on earth's surface is covered by C4 plants. A handful of crops which can utilize this process include maize, sorghum, sugarcane, millets, sour grasses.

During the evolution of C_4 photosynthesis, another CCM is frequently associated with an transitional physiological state called C_2 photosynthesis, present in C_3-C_4 intermediates (Schlüter et al. 2017). C_2 photosynthesis can hasten the CO_2 assimilation by arresting, concentrating and re-assimilating CO_2 released by photorespiration (Lundgren 2020). C_2 photosynthesis relies on shuttling of photo respired glycine from peroxisome of mesophyll cell into mitochondria of bundle sheath where it becomes decarboxylated by glycine decarboxylase (GDC) enzyme and release CO_2 for re-assimilation via Calvin cycle in BS chloroplast (Keerberg et al. 2014). As a result, the C_2 CCM improves net CO_2 assimilation rate in C_3 plants in high light, limited CO_2, and warm environment (Bellasio and Farquhar 2019). Both the phenotype and ecology of C_2 plants may enable the evolution of C_4 photosynthesis in a frontward path (**Fig.1**).

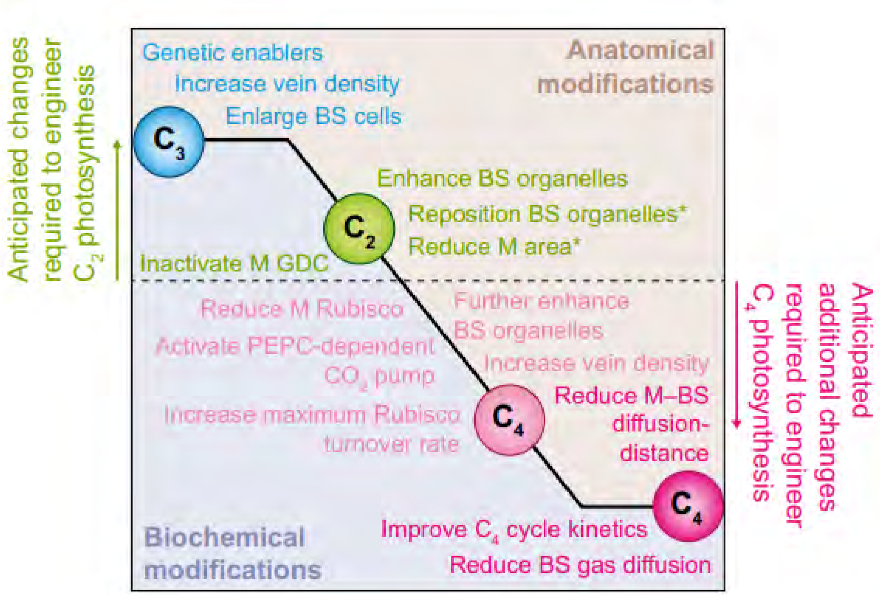

Figure 1. Progressive structural and biochemical adaptation intended for the development of C3, C2 and C4 photosynthetic type (Adapted from **Lundgren et al 2020**) in land plants

3. Is C_2 engineering can be an alternative to C_4 engineering?

C_2 photosynthesis has been revealed in 50 species from 4 monocots and 16 eudicot lineages, presenting 11 plant families, including Amaranthaceae, Asteraceae, Brassicaceae, and Poaceae.

C_2 plants generally exhibit high photosynthetic rate and water- and nitrogen-use proficiencies as related to C_3 crops. Plants showing C_2 photosynthesis can accomplish under different environmental situations which favour either C_4 or C_3 pathway (i.e., high or low CO_2 environments, respectively) (**Fig.2**). Photorespiratory CO_2 loss affects crop productivity by reducing yield > 20% in C_3 plants. As C_2 plants experience a reduced amount of net carbon loss from photorespiration, altering this pathway into C_3 rice could have a huge impact on crop yield and productivity. A physiological characterization of C_2 rice (Bellasio and Farquhar 2019) suggested that effect of C_2 photosynthesis can enhance the net CO_2 assimilation rate under reduced CO_2 concentrations (< 400 µmol mol^{-1}), high light (> 700 µmol m^{-2}s^{-1}) and warm temperature (> 35°C) as compared to C_3 rice. Conversion of C_2 photosynthesis into C_3 crops may carry some physiological adaptableness to withstand in the changing climate. C_2 photosynthesis provides some additional advantages over C_4 photosynthesis along with few anatomical modifications suggesting that engineering of C_2 photosynthesis in C_3 rice is more amenable than C_4 (Gowik and Westhoff 2011), as the increasing leaf vein density may not be necessary in C_2 photosystem.

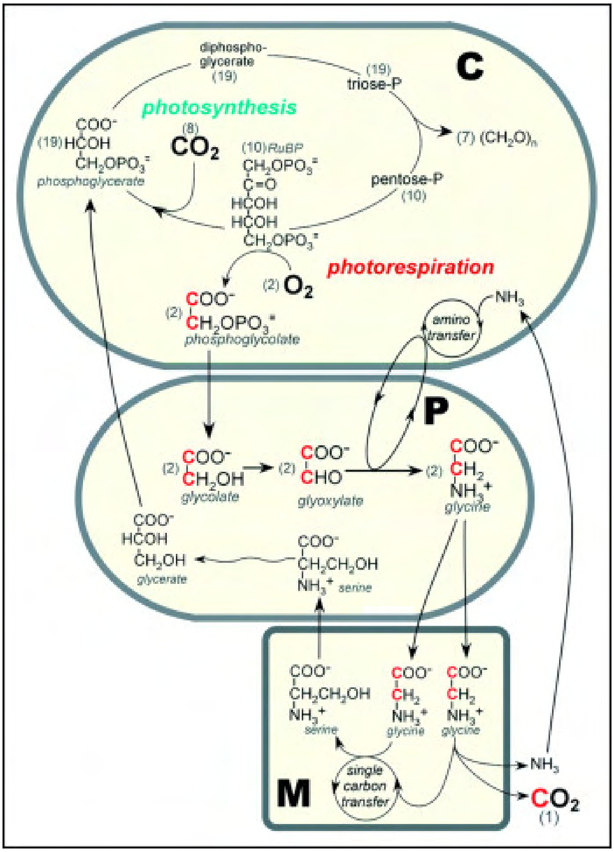

Figure 2. An illustration of Photorespiratory C_2 pathway. Three different organelles such as chloroplast, mitochondria, and peroxisome are involved in C_2 pathway operation, highlighted with three different colors. RuBP oxygenation leads to the generation of 2-PG (Phosphoglycolate) which is recycled to produce glycerate. (Adopted from **Ogren, W. L. (1984) Annu. Rev. Plant Physiol. 35, 415–442**)

4. C_4 Carbon Cycle

Enzymes associated with the C_4 pathway present in C_3 plants but are involved in other metabolic course (Aubry et al. 2011). The exclusive C_4 photosynthetic enzymes are more biologically active in C_4 plants as compared to the C_3, where C_4 specific isoforms have different enzyme kinetics with respect to their C_3 counterparts (Ludwig and Burnell 1995). This C_4 cycle needs two cell architectures (Haberlandt, 1904), associated by plasmodesmata. Primary carbon fixation occurs in the external layer of photosynthetic tissue (mesophyll cell) and secondary fixation occurs in an inner layer (bundle sheath cell) after decarboxylation by Rubisco (**Fig.3**).

In C_4 photosynthesis, atmospheric CO_2 is changed to bicarbonate by the enzyme carbonic anhydrase (CA) in the cytosol of mesophyll cell. This bicarbonate (HCO_3^-) is then fixed by phosphoenol pyruvate (PEP) in presence of enzyme, phosphoenolpyruvate carboxylase (PEPC) to produce a C_4 compound, oxaloacetic acid (OAA). OAA is transformed to either malate or aspartate by malate dehydrogenase (MDH) or by aspartate aminotransferase (Pick et al. 2011) respectively and then diffuses into chloroplast of bundle sheath cells through plasmodesmata (Kanai 1999), where OAA is decarboxylated to form pyruvate and release CO_2 at the vicinity of Rubisco to carry out the Calvin cycle (Von Caemmerer 2000). After decarboxylation, the pyruvate disseminates back to the mesophyll cell to generate PEP by pyruvate phosphate dikinase (PPDK) which is then used by PEPC to endure the C_4 cycle (Schlüter and Weber 2016).

Basically, C_4 photosynthesis is divided into three subtypes viz. NADP-ME, NAD-ME and PEPCK on the basis of decarboxylating enzymes used. In NAD-ME and PEPCK subtypes, aspartate is transported to the BS cells (Furbank 2011) where it reforms oxaloacetic acid (OAA) in cytosol and mitochondria (Taniguchi et al. 1995). In case of NADP-ME type C_4 species (*Z. mays, S. bicolor*) malate is synthesized in chloroplasts of mesophyll cells and decarboxylated by NADP-ME in bundle sheath mitochondria to generate pyruvate and $CO_{2.}$ NADH produced in this reaction is used to generate ATP in mitochondria to accelerate the PEPCK reaction (Hatch 1988). In the NAD-ME types (*C. gynanadra*, *M. maximus*), oxaloacetic acid (OAA) is converted to malate by MDH, and subsequently malate is catalysed by NAD-ME to generate CO_2 and pyruvate in mitochondria. Plants with PEPCK subtype (*P. maximum*), both malate and aspartate are used as transport metabolites and decarboxylation occurs in presence of both phosphoenol pyruvate carboxy kinase (PEPCK) and aspartate amino transferase in cytosol of BS. NADP-ME and PEPCK species have higher quantum yield efficiency as compared to NAD-ME species (PEARCY and EHLERINGER 1984). NADP-ME shows higher nitrogen use efficiency with respect to other two subtypes (Pinto et al. 2016).

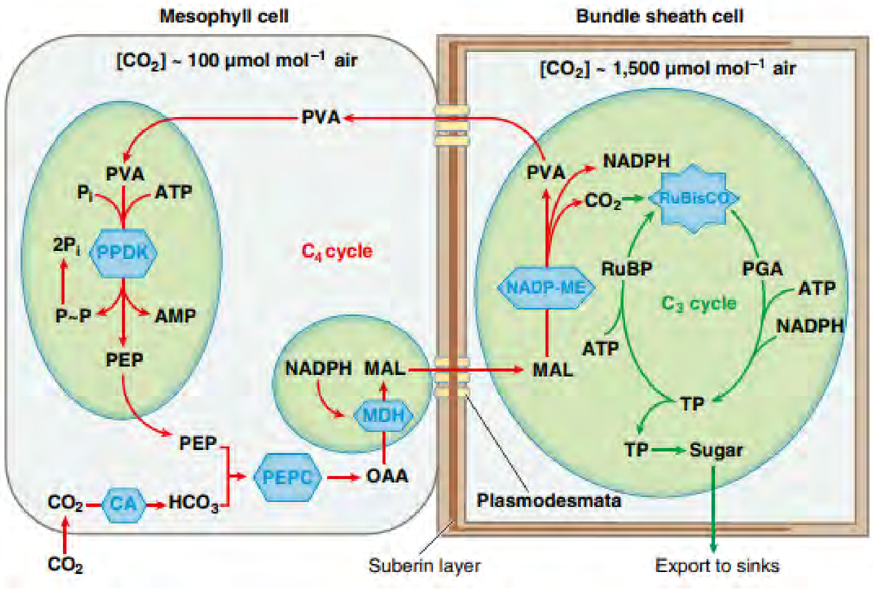

Figure 3. C_4 photosynthesis cycle. The principal reactions of C4 photosynthesis involves a carbon shuttle between two different cell types i.e., a mesophyll cell (left) and a bundle sheath cell (right) [Adapted from **Kellogg et al 2013, Current biology; Volume 23, Issue 14**]

5. Progress in Building C_4 anatomy and biochemistry:

Incorporation of C_4 photosynthetic traits into C_3 crops is an approach to generate enhanced photosynthesis and yield. Multiple changes are required to establish a functional C_4 like characters in C3 crops, such as to engineer leaf anatomy, vein density, increased density of functional photosynthetic pigments in the vicinity of bundle sheath cells (Lin et al. 2020). Recently, an approach was undertaken to engineer rice for C_4 like character by incorporating total sorghum DNA in transgenic rice using spike stalk injection method. Introduction of foreign DNA into rice resulted into Pro Kranz anatomy like feature as similar to C_4. Increased number of bundle sheath, chloroplast, and leaf thickness was also observed in transgenic rice lines (Jiang 2021). A detailed leaf anatomy between C_3 and C_4 highlights that C_4 bundle sheath were highly packed with functional chloroplast, whereas C_3 harbors vacuolated and barely occupied chloroplast (Ermakova et al. 2020). However, the overexpression of transcription factor genes, such as GOLDEN2 (G2) and GOLDEN2LIKE (GLK) into transgenic rice resulted into the development of partial C_4 like leaf character viz. increased abundance of chloroplast in the bundle sheath (Wang et al. 2017). Less vein spacing and lower number of mitochondrial chloroplasts was observed in C_4 leaves as compared to C_3 (Stata et al. 2016). Previous study revealed 30% increment in flag leaf content due to overexpression of Cytokinin Responsive Gata Factor-1(CGA-1) in transgenic rice (Hudson et al. 2013). The size of the bundle sheath cell does not vary significantly between C_3 and C_4 plants but bundle sheath area per leaf appears to be a major governing factor. Increased vein number in leaf blade, reduction in interveinal distance, and mesenchymal cells between the veins can promote the C_4 like behavior in C_3 rice (Hughes et al. 2019). C_4 genes which promote anatomical modification, upon incorporation may rejuvenate the C_4 pathway in C_3 rice. A complete functional C_4 biochemical pathway with cell specific expression and regulation of genes is essential to establish C_4 like trait in rice. Two independent reports revealed the possible establishment of C_4 pathway in rice by overexpressing the key C_4 enzymes (Lin et al. 2020) (Ermakova et al. 2021). However, simple overexpression of enzymes involved in the C_4 metabolic pathway is not sufficient to get C_4 like character, imbalance of which showed detrimental consequences in the entire metabolic pathway. Cui et al 2021 suggested two approaches for establishing C_4 like metabolism in the C_3 plants for enhanced photosynthesis. The first approach is by increasing the PEP concentration along with maintaining the PGA content in the chloroplast of mesenchymal cells to secure active substrate concentration for the PEPC catalyzed reaction. The other aspect was to maintain proper oxidation state in the BSC to enable an efficient malate decarboxylation through NADP-ME. These strategies with proper C_4 enzyme localization will be helpful to improve the C_4 photosynthesis and C_4 rice engineering (Cui 2021).

6. Efforts in engineering C_4 photosynthesis in rice through transgenesis

C_3 crops are major calorie producers (i.e., rice and wheat) (Alberto 1996) and rice is considered to be a main source of carbohydrate in tropical region, where 70% of global population living under poverty line. So, it is necessary to enhance the productivity of rice to feed ever-increasing global population. Modification in photosynthesis can boost the crop productivity (Kromdijk 2016). However, this requires rearrangement of leaf anatomy and regulation of gene expression. Given the high solar energy conversion ability of C_4 photosynthesis, constructing the C_4 pathway in rice is thought to be a novel approach to improve rice yields. Therefore, many attempts have been made to engineer C_4 pathway in rice to improve its photosynthetic efficiency in changing climate (Shen et al. 2019).

In recent years, there has been increased emphasis on rice transformation with C_4 photosynthetic genes. Carbonic anhydrase and phosphoenolpyruvate carboxylase (PEPC) play a pivotal role in the primary CO_2 assimilation in C_4 plants. Earlier reports revealed that overexpressing C_4 PEPC in rice had influential effect on rice physiology and growth. To know about the role of PEPC in stomatal distribution in C_4 leaf, *Setaria viridis* transformants were developed using RNAi interference to target the cytosolic photosynthetic PEPC isoform to reduce PEPC activity (Alonso-Cantabrana et al. 2018). *S. viridis* lines showed reduced PEPC activity with increased stomatal density between mesophyll and bundle sheath cells, and decreased cell wall thickness. The transgenic lines required high ambient CO_2 concentrations for growth, consistent with the indispensable role of PEPC in C_4 photosynthesis. It has been hypothesized that alteration in stomatal density is because of the development of C_4 photosynthetic flux.

Engineering of *ZmPEPC* in rice showed increment in PEPC activity in cytosol of mesophyll cell which is 25 times higher in PEPC expressing rice lines as compared to wild type. But there were no differences in net photosynthetic rate (Giuliani et al. 2019). Such findings were consistent with the previous report where overexpression of single C_4 genes in rice has no immediate effect on plant growth or CO_2 assimilation rate (Karki 2020). However, recent research finding revealed that transgenic indica rice cultivar expressing C_4 PPDK and NADP-ME genes from *Seteria italica* exhibited higher chlorophyll accumulation and improved photosynthetic performance along with other related attributes. Transgenic plant lines resulted better agronomic traits over the wildtype (Swain 2021).

It was thought that single C_4 gene expression may not be sufficient enough to improve the CO_2 assimilation rate in rice. So, a quadruple line was developed that accumulates four C_4 major photosynthetic enzymes from *Zea mays* (i.e., *ZmPEPC, ZmNADP-MDH, ZmNADP-ME* and *ZmPPDK*). Cumulative expression of these genes intensified the enzyme activity but had neutral effect on CO_2 assimilation rate. This finding suggested that installation of correct leaf anatomy along with transgene expression are essential to facilitate a fully functional C_4 cycle in rice (Lin et al. 2020). In the same way, a japonica variety, Kitaake was transformed with four C_4 photosynthetic genes (CA, PEPC, NADP-MDH, PPDK and NADP-ME) from maize within a single construct under the control of cell-specific promoters (Ermakova et al. 2021). Regulation of gene expression is principally controlled by the cis-acting elements present at the 5' region of the target gene. Therefore, tissue specific promoters are important for driving the expression of C_4 genes in C_3 crops. Less than 50% of transformed plants showed expression of all five genes. The result highlighted three independent homozygous lines had higher malate and aspartate content as compared to wild type, showing significant rise in CO_2 fixation in *ZmPEPC* expressing rice lines. PEPC and MDH activity in these lines were increased significantly (2-3 and 10-fold respectively). Among the five genes, the accumulation level of NADP-ME was lowest in the transformed lines.

To unravel the functional significance of PEPC in carbon and nitrogen metabolism, sugarcane C_4-PEPC gene was overexpressed in rice (Lian et al. 2021). The study revealed increment in total nitrogen content in transgenic rice lines when compared with wild type counterpart. Phenotypic evaluation revealed development of short primary root system at the seedling stage. This study also revealed that overexpression of sugarcane PEPC brings about significant changes in gene expression pattern, enzyme activity, metabolites and availability of phytohormones in transgenic rice lines. Measurement of metabolic intermediates involved in glycolysis, TCA, nitrogen metabolism revealed changes in nitrogen uptake in transgenic rice lines at different nitrogen source condition. In addition, "glutathione (GSH) metabolism", which mainly contains GSH S-transferase was reported in transgenic rice where GST activity decreased with the accumulation of GSH (substrate) under normal condition. Accumulation of GSH raised the glutathione level in transgenic rice which played a critical role in GOGAT cycle in ammonium assimilation pathway. Furthermore, levels of phytohormones (IAA, zeatin and isopentenyladenosine) were significantly reduced in the roots under available nutrients (Lian et al. 2021).

7. Genome editing for enhancement of photosynthesis

CRISPR-Cas mediated gene editing approach was used successfully for enhancement of photosynthesis in rice. Recent report highlighted that a rice hexokinase gene (*OsHXK1*) was mutated using CRISPR/Cas9 in three indica rice cultivars (Zheng et al. 2021). Phenotypic analysis and agronomic trait evaluation revealed that mutant plants showed high light saturation points, increase in stomatal conductance, enhancement in photosynthetic products, and yield parameters. Transcriptome profiling showed up-regulation of significant photosynthesis-related genes in the mutant indica rice lines as compared to wild type (Zheng et al. 2021).

8. Conclusion

In due course of evolution of C_4 photosynthesis, many changes in C_3 metabolism occured slowly including upsurges in bundle sheath decarboxylation activity, C_4 enzyme production in the mesophyll cells, altered Rubisco activity in bundle sheath, and structural changes of leaf anatomy. Hence, establishment of C_4 rice requires engineering of essential components involved in C_4 pathway into cultivated rice variety, and then adjusting leaf architecture and related metabolite transport system essential for high efficiency C_4 pathway of carbon fixation. This approach is confined due to inadequate knowledge about the genetics behind reconfigurations of Kranz anatomy, anatomical perturbation in establishing a functional C_4 pathway into C_3 rice (Sedelnikova et al. 2018). Bringing those changes in C_3 plants is a incessantly challenging task. Large scale transcriptome and proteome analysis will delineate the identification of key genes related to photosynthesis, and yield, which can provide the platform for putative gene identification. Subsequently, overexpression and CRISPR-mediated functional validations will ensure the possible direct or indirect involvement of genes in C_4 photosynthesis and yield related parameters.

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Chapter 04

Biofortification in Rice for Vital Nutritional Traits: Present Status and Potentiality in Downgrading Malnourishment

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Abstract

Rice is the staple food and source of nutrition of half of the world population. It is usually consumed as milled rice which in general is deficient in micronutrients, vitamins, protein and antioxidants. This compilation mainly focus on how diversity of these nutritional traits among cultivated and wild rice germplasm are being tapped in mapping, identification of functional genes and genetic modification in finally for development of bioforified rice varieties. Nutritional importance of grain protein and micronutrients and recent development in rice research for improving the level of these traits especially in India is given emphasis in this chapter. Reaching of biofortified rice to the unprivileged section of our population is the prime important step for achieving the target of much desired nutritional security for the developing world.

Keywords: Rice breeding, Grain protein content, micronutrients, essential amino acids, antioxidant, vitamins, nutrient-rich rice, nutritional security

1. Introduction

Globally more than 24,000 people die daily due to "hidden hunger" and malnutrition (Fiaz et al. 2019). Approximately one-third of the world's population is facing the problem of hidden hunger (White and Broadley 2009). Increasing the risk of mortality as well as affecting fatal growth due to malnutrition during pregnancy results in low birth weight (LBW), risk to survive the child. The occurrence of malnutrition in developing and underdeveloped countries remains a major public health issue (UNICEF 2007). The joint estimates (UNICEF 2020), published in March 2020 by UNICEF and WHO stunting, wasting and overweight among children below the 5 years of age. That revealed inadequate progress to reach the World Health Assembly targets set for 2025 and also the Sustainable Development Goals set for 2030. In 2019, more than half of all stunted children under the age of 5 years lived in Asia. Severe level (>30%) of stunting among children is found in India. In India wasting syndrome among children is also very high (10-15%). Prolonged utilization of carbohydrate-rich food mainly based on rice, wheat, or maize is contributing to such nutritional deficiency in poorer section of our society as most of them are unable to supplement nutritionally rich food for their diet. The deficiency of micronutrients can be termed as a silent epidemic because it slowly weakens our immune system and hampers physical and intellectual development. Rice is one of the most important staple foods among all cereals. People are found to bank on rice as their main source of nutrition in developing and underdeveloped countries (Yang et al. 2016). The larger population in Asia and Africa depends on rice for their daily calorie and nutritional requirements. In India for more than 70% population rice is the staple food. Rice grain contains all edible portions with 6.8g of protein, 0.5g of fat, 78.2g of carbohydrate and 345 K cal of energy per hundred grams of rice (Juliano and Bechtel 1985). But, it is considered that the milled or polished rice is nutritionally poor as the majority of the essential micronutrients *viz.* iron (Fe) and zinc (Zn) and important vitamins are lost during the process of milling and polishing (Johnson et al. 2011). Iron deficiency anaemia (IDA), zinc deficiency and vitamin-A deficiency (VAD) are common among people mainly depend on milled rice for their nutrition and have serious consequences. The poorer section of the worldwide population mainly depends on rice, are most vulnerable to 'hidden hunger' are often at the maximum risk for micronutrients deficiencies (Bouis and Saltzman 2017). Rice is also relatively low in protein content (7-8%) as compared to other cereals such as wheat, barley and millets. Protein-energy malnutrition is prevalent among children those with the dietary intake of predominantly rice. The only possible solution for such malnutrition is to have nutritionally enriched food in the daily foodstuff. Biofortification in rice could be a game changer for those people who have very limited choices of dietary resources. Biofortification is a process of increasing the density of vitamins, minerals, protein and other nutrients through genetic means. Transgenic techniques and agronomic practices also are being considered for developing nutrient rich rice. Biofortification, however, has two crucial comparative advantages, viz. its long-term cost-effectiveness and its ability to reach unprivileged, rural populations. As rice is consumed by more than 50% of the world population, biofortification in rice for minerals, protein and vitamins can significantly contribute to reduction of hidden hunger in world population.

2. Grain protein and its biofortification

Protein deficiency and amino acid imbalance are identified to trigger specific health disorders affecting growth and brain development. Protein–energy malnutrition (PEM) is globally the most important risk factor for illness and death, affecting millions of pregnant women and young children. Marasmus and kwashiorkor are two forms of PEM predominant in developing countries. Human protein requirements are met mainly from plant sources and relatively less from animal source. Moreover, plant proteins are more available, relatively cheaper and easier to transport than animal's protein. As staple food, rice supplies about 30-40% of the total protein requirement of humans in developing countries. Rice is generally deficient in protein (7-8%). However, due to its balanced amino acid profile and high content (0.80) of highly nutritive and digestible glutelins, rice protein is a significant provider to meet the growing demand of high-quality cereal as a source of protein (Fitzgerald et al. 2009). Among cereals, it has a comparatively higher and balanced content of essential amino-acids. Therefore, high-protein rice has the ability to enhance nutrition for the poor in rural areas who depend mainly on rice (Li et al. 2004).

2.1 Variation in Grain protein content

Proper understanding of N metabolism and amino acid translocation are prerequisite to comprehend higher grain protein in high yielding rice genotypes. During the grain filling stage, N that is stored in the leaves, is remobilized to the developing seed, which poses a strong sink for photosynthates and nutrients. However, a negative correlation exists between grain protein concentrations and yield (Beninati and Busch 1992). Remobilizing efficiency, however is highly genotype dependent (Kichey et al. 2007). International Rice Research Institute (IRRI) evaluated 13089 *indica* accessions and protein content ranged from 4.3% to 18.2% (dry season) and 3.5% to 15.9% (wet season). This indicated wide genetic variability of this trait and scope of its improvement. Juliano and Villareal, (1993) evaluated protein content in 1622 milled rice samples from 24 countries which ranged from 4 to 14% with the overall mean of 7.8%. At ICAR-NRRI, Cuttack Mohanty et al., (2011) reported high crude protein (15-16%) in brown rice of ARC 10063 and ARC 10075 accessions on dry weight basis. Around 2000 germplasm of *Indica* rice has been evaluated for GPC at ICAR-NRRI. Kalinga-III, Heera, Mamihanger, Bindli with 11-13% protein content was detected as donors for this trait (Chattopadhyay et al. 2018). Minatik Charang (ARC 10075) was registered by the Plant Germplasm Registration Committee as high grain protein donor Nitrate reductase (NR) and Nitrite reductase (NiR) activity was higher for ARC 10075 as compared to low protein counterpart. It had also higher free amino acids (0.26%), methionine (0.082%), lysine (0.049%) and tryptophan (0.063%) (Mohanty et al. 2011).

2.2 Importance of protein quality in rice

It has been stated earlier that improvement of GPC reduced the protein quality resulting in a hardening of the cooked rice (Derycke et al. 2005). Rice protein has four fractions, namely, albumins, globulins, prolamins and glutelins. Glutelins is highest (80%) followed by prolamins (20%). Kim et al. (2013) found 1.86, 0.50, 7.31 and 0.05% albumin, globulin, glutelin and prolamin fractions, respectively in waxy brown rice. In rice endosperm, two types of protein bodies (PB) are found where storage protein accumulates. Regular, spherical PB-I contains mostly prolamins while irregularly shaped PB-II contains mainly glutelins and globulins (Ogawa et al. 1987). PB-II with higher essential amino acids is more digestible than PB-I. Therefore, glutelin is nutritionally more superior than prolamins for human beings in respect of digestibility. So, the protein quality of rice could be enhanced further by enhancing the glutelin and globulin contents (Kumamaru et al. 1988).

2.3 QTLs for grain protein content

More than hundred stable and consistent QTLs for GPC have been detected and mapped on all twelve chromosomes of rice. The majority of them were situated on chromosomes 1, 2, 6, 7, 10 and 11. But a very few QTLs have been cloned. One of them is *OsAPP6* situated inside a QTL *qPC1* (Peng et al. 2014). But its expression level was found to be associated with GPC variation only in *indica* accessions. It appeared that *OsAAP6* could be only used as a target gene to regulate GPC in *indica* breeding programs. Yang et al (2019) identify two stable quantitative trait loci (QTLs), *qGPC-1* and *qGPC-10*, controlling GPC. Map-based cloning discovered that *OsGluA2,* encoding a glutelin type-A2 precursor, is the candidate gene underlying *qGPC-10*. It functions as a positive regulator of GPC and has also a pleiotropic effect on rice grain quality. Chattopadhyay et al. (2019a) using a mapping population derived from the cross between grain protein donor, ARC10075 and high-yielding cultivar Naveen identified one stable QTL for grain protein content, *qGPC1.1* and another two stable QTLs for single grain protein content namely *qSGPC2.1* and *qSGPC7.1* explaining 13%, 14% and 7.8% of PVE, respectively. One gene *Os01g0111900*, encoding a glutelin family protein was also found inside the QTL, *qGPC1.1*.

2.4 QTLs for Amino acid

With various mapping populations useful genetic information for improving the amino acid composition (AAC) in rice grains was derived. Using recombinant inbred lines from the cross between *indica* (Milyang 23) and *japonica* (Tong88-7) rice varieties (Jang et al. 2020), 17 and 3 QTLs were detected for amino acid content and protein content, respectively. Lines with qAAC7.1 had higher Met, His, Lys, and Gly than those of both the parents (Jang et al. 2020).

2.5 Breeding and improvement of rice for grain protein content

Significant researches have been done in recent years to improve the protein content and quality of rice through conventional breeding and induced mutagenesis (Mahmoud et al. 2008, Khush and Juliono 1984). In earlier rice breeding programme for developing high protein elite lines at IRRI, pedigree and long cycle recurrent selection were followed and one elite line IR480 was identified with a higher percentage of grain protein than IR8 and same grain yield as IR8.Mahmoud et al. (2008) found a significant increase in seed protein content in an interspecific hybrid between *Oryza sativa* ssp. *indica* and the wild species *Oryza nivara*. ICAR-NRRI, Cuttack has developed a few high yielding breeding lines with substantial improvement of grain protein content over the high yielding varieties through bulk-pedigree breeding methods (Chattopadhyayet al., 2018). Cypress, an LSU AgCenter-bred semi-dwarf long grain rice known for its excellent grain quality was used to develop and release high protein rice variety, Frontière, in 2017 in USA. It has an averages 10.6% protein which is 54% more than most conventional long-grain rice varieties.Apart from conventional breeding transgenic approach also followed to develop lysine rich rice. Liu et al. (2016) expressed a LYSINE-RICH PROTEIN gene (LRP) using an endosperm-specific GLUTELIN1 promoter (GT1) in Peiai64S (PA64S), an elite photoperiod-thermo sensitive male sterility (PTSMS) line. Endosperm-specific expression of foreign LRP significantly increased the lysine content in the seeds of transgenic plant. The hybrid of the transgenic plants also displayed substantial increases of Lys content in the seeds.

2.6 Development of high protein varieties through backcross breeding- a case study

Backcross method of selection was proved useful for developing elite introgession lines and is quite effective in generating transgressive segregants for desired trait in the background of the high yielding recurrent parent. Backcross also helps to reduce the effect of undesirable traits. ICAR-NRRI used one land race (ARC10075) as high GPC donor and exercised three repeated backcrossing with recurrent parents, Swarna and Naveen for developing two backcross populations. BC_3F_1 plants were selfed and population was carried by single seed descent (SSD) method which was reported efficient not only for speeding up and economize the breeding process but also for producing wide range of phenotypic variation with high level of transgressive segregation. Except one, all high-protein lines had significantly higher glutelin content than Naveen. Higher accumulation of glutelin ensured better protein quality in most of these lines. Most of the high-protein lines had similar or slightly lower values in prolamin/ glutelin ratio than the parents which safeguarded the cooking quality of these introgression lines (Chattopadhyay et al. 2019b). Most of the high-protein lines had considerably higher levels of lysine, threonine, leucine, isoleucine, valine, phenylalanine, alanine, proline, glutamate, arginine and total amino acid compared to recurrent high-yielding parents. Higher levels of some of the essential amino acids in the introgressed lines showed superior quality of storage protein. This qualitative improvement has been earlier largely limited to maize crop through enhancement of grain lysine in QPM lines and has now been extended to rice. The following biofortified rice varieties with elevated level of grain protein content was developed and released by ICAR-NRRI, Cuttack.

a. CR Dhan 310 (IET24780): It has been developed and released in India as the first high protein rice variety for the states of Odisha, Uttar Pradesh and Madhya Pradesh in 2016. It is in the background of high yielding variety cv. Naveen. It has medium duration (120-125 days), semi-dwarf plant type (110 cm) with medium slender and good grain quality. The average grain yield is 4483 kg/ha and it contains average 10.2% protein in polished rice.

b. Mukul (CR Dhan 311: IET 24772): It has been released and notified for Odisha as nutrient rich rice in 2019. It is also in the background of cv. Naveen. It has high protein content (10.1%) and moderately high level of Zn content (20 ppm) in 10% polished rice with 5542 kg /ha grain yield in Odisha. It has also medium duration (120-125 days), semi-dwarf plant type (110 cm) with long bold grain and good cooking and eating quality.

c. CR Dhan 411 (Swarnanjali) (IET 26398: CR Dhan 2830-PLS-17): This is released in 2021 in Odisha. It is in the background of high yielding variety Swarna (MTU 7029). It had 5621 kg/ha average grain yield. It showed the average protein content and protein yield of 10.01% and 529.2 kg/ha, respectively which were 29% and 31% higher than Swarna.

3. Role of micronutrients – Fe and Zn in nutrition and genetic enhancement in milled rice

Zn deficiency in grown-up children and adolescent males triggers stunted growth and dwarfism, retarded sexual development, poor appetite and mental lethargy (Hambridge 2000). It has been found that Zn is essential for gene regulation as well as expression under stress conditions, ensuring protection against biotic and abiotic stresses (FAO 2005). The world is now a days facing a pandemic caused by a novel coronavirus. The infection is known to more severely affect senior people with various chronic comorbidities such as COPD, obesity, hypertension and diabetes. Zinc has a known role in the regulation of immunity. Zinc has shown its ability to inhibit SAR-CoV RNA polymerase (teVelthuis et al. 2010). Zinc ions inhibited SARS-CoV RNA-dependent RNA polymerase. More than 50% reduction in overall RNA synthesis was detected at zinc levels of 50µM. Hypothetically, zinc deficiency could expedite SARS-CoV-2 infection of target cells due to an increase in angiotensin-converting enzyme 2 (ACE2) activity that could facilitate binding with SARS-CoV-2 (Mayor-Ibarguren et al. 2020). Fe is an important micronutrient for both plants and animals and deficiency of Fe is one of the predominant micronutrient deficiencies which causes ~0.8 million deaths annually worldwide. Iron has so many vital functions in the body such as a carrier of oxygen to the tissues from the lungs. Fe deficiency is ranked in the sixth position among the risk factors for death and disability in developing countries with high mortality rates. Biofortification of rice could be an appropriate approach to improve Fe-deficiency anemia which is a serious health problem in developing countries where rice is the main staple food (Juliano 1993).

3.1 Variation of micronutrient content in rice

Selecting genotypes with high efficiency of Fe and Zn accumulation from existing germplasm collection could be a credible approach to provide direct benefit of micronutrient nutrition to farmers and consumers and also tools for the breeders for evolving high yielding nutrient rich rice (Dikshit et al. 2016). Indigenous germplasm (Pusadee et al. 2009) are reported to be rich sources of iron (Fe) and zinc (Zn) content. Zinc content in the germplasm from 16 national institutions evaluated at ICAR-IIRR ranged from 7.3 to 52.7 mg/kg. The mean values of zinc content in brown rice ranged from 15.9 to 27.3 mg/kg. Among the germplasm, wild rice, landraces, and *aus* accessions were found to be a valuable source of micronutrients (Cheng et al. 2005, Descalsota-Empleo et al. 2019). *Aus* accessions, being genetically closer to popularly grown *indica* rice varieties can be readily used in biofortification programme. The concentration of iron in brown rice was 19 ppm became deceased to around 4 ppm in polished grains (Masuda et al. 2009). This evident reduction of iron in consumable rice grain is the concern and make the iron biofortification difficult through conventional approach.

3.2 Improvement for Fe and Zn

In last two decades, more than 100 QTLs have been detected and mapped on all 12 chromosomes for zinc and iron contents in rice grain using various mapping populations developed from different intraspecific and interspecific crosses. The QTLs detected on chromosome 7 provided 5.3–35.0% of the phenotypic variance for Zn content in various backgrounds, while the QTLs on chromosome 12 contributed 9–36% (Swamy et al. 2016). Recently, association mapping using diversity panels for Zn content headed to the detection of seven QTLs on chromosomes 1, 2, 4, 6, 7, and 12 and three QTLs on chromosomes 1, 5, and 7 by Zaw et al. (2019). Sanghamitra et al. 2022 found that among nutrient-rich germplasm of Odisha, some were moderately high grain yield such as Champeisiali which contained high Fe (44.1 ppm) and Zn (27.39 ppm) along with moderately high grain yield (20 g/plant). Therefore, enhancement of Fe and Zn content in rice grain without affecting its grain yield is feasible. It was suggested by Swamy et al. (2016) that high Zn donors with acceptable yield level could be used in crossing with high yielding varieties and selection of suitable high yielding high Zn segregants from F_4 generation onwards could accelerate the process of developing high yielding biofortified variety with high Zn. Advanced backcross breeding also was suggested to transfer high Zn trait from un-adapted donors to high yielding rice varieties. Recently released high yielding varieties with high Zn content such as CR Dhan 311, DRR Dhan 45, DRR Dhan 49, CR Dhan 315, Chhattisgarh Zinc Rice-1, etc. under biofortification breeding programme exercising backcross, pedigree and bulk-pedigree breeding methods indicated the evidence of successfully combining high yield with high Zn content in rice. Some of these biofortified varieties are as follows.

- ***DRR Dhan 45***: First high zinc variety notified in India. It is semi-dwarf medium duration (125 days) for irrigated conditions. Zn content is 24.0 ppm in polished rice. It was released for Tamil Nadu, Andhra Pradesh and Karnataka with grain yield of 5.2 t/ha.

- ***Chhattisgarh Zinc Rice-1***: It has a average 22 ppm Zn content in milled rice. It is semi dwarf (95-100 cm height) in nature and early mature in 105-110 days. It has long bold grains and selected for 'direct seeded rainfed, aerobic and irrigated Ecosystem' of Chhattisgarh plains.

- ***CR Dhan 315 (IET 27179: CR 2826-1-1-2-4B-2-1):*** It is released and notified for the states of Gujarat and Maharastra as biofortified rice variety. It contains average 24.9 ppm zinc in milled rice in zone VI. It has medium duration (125-135 days), semi-dwarf plant type (110 cm) with medium slender grain and good grain quality. It is suitable for irrigated and favorable shallow rainfed ecology. National average of grain yield of this variety is 5054 kg/ha.

Biofortification programme have resulted in the successful release of several high-Zn rice varieties in several countries of Asia. Five high-Zn rice varieties such as BRRI Dhan 62, BRRI Dhan 64, BRRI Dhan72, BRRI Dhan74 and BRRI Dhan 84 have been released for cultivation in Bangladesh. In Philippines and Indonesia, NSIC Rc 460 and Inapari Nutri Zn, respectively have been released. All these high-Zn rice varieties have higher grain-Zn (>24 ppm) content along with suitable agronomic traits and biotic and abiotic stress tolerance (Swamy et al. 2016). Several promising high-Zn lines have been successfully tested in Myanmar and Cambodia and in some African countries. In addition to that several gene specific markers such as *OsZIPl, OsZIP3, OsZIP4, OsZIP5, OsZIP8, OsNAS1, OsNAS2, OsNRAMPl*, etc. showed a very decent correlation with grain Zn content (Chandel et al. 2011). Marker assisted breeding for high Zn rice using major gene/ QTL based markers also could be a faster and meticulous approach.

High iron content rice such as IR 68144, was bred through molecular breeding approaches by overexpressing soybean ferritin gene registered to increase iron content in milled rice grain by 3.7-fold (Vasconcelos et al. 2003). Recently, Paul et al. (2014) successfully transferred this trait to Indian mega rice variety Swarna, resulting in 2.54-fold more iron in milled rice grain as compared to control Swarna.

4. Phytic acid and improvement of bioavailability of nutrients

Phytic acid or myo-inositol hexaphosphahe is a compound that can chelate divalent cations like Fe^{2+}, Mg^{2+}, $Zn^{2+,}$ or Ca^{2+} and thereby reduces the bioavailability of these ions in the human diet. Except maize, in most of the cereals including rice, it is predominantly accumulated in the aleurone layer of the grain. The phytate content in the rice grain is one of the important determinants of the bioavailability of important minerals like iron and zinc. Over the years studies showed that some of the rice varieties/ germplasm accessions are having low phytate content (Kumar et al. 2019). Also, there were a few attempts rice by generating mutant varieties exhibiting a low phytic acid (lpa) phenotype in rice (Kim et al. 2008), which were although effective to produce low grain phytate content, but were having compromised yield and other agronomic traits. So, as an alternative strategy, transgenic lines were developed by manipulating the genes of key enzymes of the phytic acid biosynthetic pathway using RNAi technology (Ali et al. 2010; Karmakar et al. 2019).

Ali et al. (2010) developed Pusa Sugandhi II *indica* rice cultivar by regulating the expression of inositol-1,3,4,5,6-pentakisphosphate 2-kinase (IPK1) of phytic acid metabolism by silencing *IPK1* gene employing Ole18 seed-specific promoter using RNAi technology.

5. Pro-Vitamin A biofortification in rice

Along with a few micronutrients, rice grain is also deficient in provitamin-A. Vitamin-A is generally produced from beta-carotene and plays a pivotal role in maintaining physiological functions in the animal body like vision, growth, reproduction, cellular differentiation, and immunity. It is also essential for adult gene regulation. Animals cannot produce carotenoids in their body and for these they dependent on plants. The majority of cultivated rice grown in lands are produced beta-carotene in their leaves and stems, but not in the endosperm. Molecular analysis and detailed studies in this regard have identified the process of beta-carotene synthesis is blocked in the endosperm. Therefore, predominant consumption of rice for fulfilling energy and nutritional demands often promotes vitamin-A deficiency in animal bodies. Vitamin-A deficiency is important due to its association with night blindness and body immunity (Tang et al. 2009). Based on the reports, worldwide, 250 million pre-school children lost their eye-sight yearly, due to deficiency of vitamin-A and 10% of these due to increased sensitivity to infectious diseases (Krishnan et al. 2009; Brown and Noelle 2015). Therefore, the development of a rice genotype, which meets the Vitamin-A demand of those poor people's is considered as a prime need for rice grain improvement programme and could be a hope to combat Vitamin-A deficiency.

To combat this issue and to alleviate the bioavailability of vitamin-A in rice endosperm, initially, Ingo Potrykur and Peter Beyer started their work and developed rice with golden endosperm, which is popularly known as 'Golden rice'. The Golden rice is named due to its yellowish colour of kernels or polished grain. This novel variety can accumulate provitamin-A in the endosperm. Later, other scientists from IRRI (International Rice Research Institute) and different parts of the world also performed this process to improve the overall carotenoid content of rice endosperm. After its development, Golden rice has gone to several obstructions and difficulties for its field release as it is developed employing the transgenic approach. Therefore, bio-safety measures and nutritional assessment process were much prolonged here comparatively than conventional breeding. Based on the most recent reports, BRRI (Bangladesh Rice Research Institute) developed BRRI dhan29 for the production of carotenoids in rice endosperm, also very close to release this genotype infield for the production of carotenoid enriched rice grains (Amna et al. 2020).

6. Folate biofortification

Folates (vitamin B9) jointly refer to a group of structurally related folate derivatives. Folates act as cofactors in one-carbon metabolism, essential for amino acid and nucleotide metabolism (Yu and Tian 2018). Notably, folates work a critical role in neurotransmitter formation and neural tube growth in humans (Imbard et al., 2013). The dietary requirement (RDAs) for folates is 400 mg/day for adults and 600 mg/day for pregnant women (WHO, 2004). Plants serve the chief dietary sources of folates. To establish the natural variations of folates in cultivated rice, the folate content was estimated in 78 rice varieties by Dong et al. (2011) and about eight-fold difference in folates was found in both brown and milled grains. The folate levels was found generally lower in milled grains (up to 78 mg/100 g DW) as compared to whole grains (up to 111 mg/100 g DW) (Dong et al., 2011). Major effect QTLs associated with high folate content in milled rice grains was detected in recombinant and backcross derived lines (Dong et al., 2014). But, those QTLs could not be mapped to the chromosomal regions of folate biosynthetic genes (Dong et al., 2014). Overexpression of folate biosynthetic genes was found quite effective in increasing folate levels in transgenic rice (Strobbe and Van DerStraeten, 2017).

7. Antioxydative compounds and their potential role in human nutrition

The brown rice contained higher amount of bioactive compounds such as phenolic acids, falvonoids, γ -oryzanol, anthocyanin, aminobutyric acid etc. along with protein, fat, minerals and vitamines as compared to milled rice. Therefore, unpolished brown rice or its derived products has significant potential of health benefits such as antioxidant, antidiabetic, anticancer, neuroprotective, and cholesterol lowering effects (Pang et al. 2018, Saleh et al. 2019). In addition, increasing demand for dehuled pigmented rice and its by-products from food, health, and cosmetic industries, which has created market and export opportunities for rice-producing countries in Asia (Issara and Rawdkuen, 2017).anthocyanin content in the pericarp of black rice was reported to regulated by *Ra*, *Rc*, *Rd*, *Kala1*, *Kala3*, and *Kala4* genes (Winkel-Shirley, 2001), of which *Kala4* produces purple or black pericarp in the complementation of *Kala1* and *Kala3* (Maeda et al, 2014).The proanthocyanidin content in rice causes red colour to rice pericarp and is controlled by *Rc* gene that encodes bHLH protein and is located on 42.6–47.7 cM of chromosome 7 and *Rd* genes that encodes a dihydro flavonol reductase (DFR protein) is found on 103.7–106.2 cM of chromosome 1 (Furukawa et al., 2006, Sweeney et al. 2006). Anthocyanin that causes purple/black pericarp to rice grain is controlled by two loci, *Pb* (Prp-b) and *Pp* (Prp-a), located on chromosome 4 and 1, respectively. Wang and Shu (2007) fine mapped *Pb* gene on rice chromosome 4 responsible for purple colour.

For human body selenium is also an essential element playing significant role in body antioxidation system; it is considered individual antioxidant that can collaborate with other antioxidants, such as vitamin C and vitamin E resulting in protecting the cells from free radicals. In such manner selenium defends a body from progression of cancer, cardiovascular diseases and masculine sterility. Selenium deficiency is linked with speeding up of senility and development of Alzheimer´s disease. Selenium affects in a helpful manner human mind and mental wellness (Kvíčala et al. 2003).

8. Conclusion

It is well recognized that biofortification is a promising, cost-effective strategy for genetically improving the nutrient status of staple crops leading to the reduction of malnourishment among populations throughout the world. Rice being staple food for a large section of population in the world is an important source of nutrition and calorie. But especially milled rice lacks minerals and other nutrients. The generation of biofortified rice with improved nutrient contents such as increases in protein, iron, zinc, Selenium, and vitamins has potential to add significant level of micronutrients and other nutrients in the diets of the developing world. International initiatives, such as the HarvestPlus program, national (Indian) initiatives such as CRP in Biofortification programme (ICAR), and many such programmes taken by various nations are contributing profusely to achieve these targets. Many biofortified rice varieties at national and International level are being released and accepted by producers. Inclusion of these biofortified varieties in different government sponsored programmes such as National Food Security Mission, *Rashtriya Krishi Vikas Yojna,* Integrated Child Development Services scheme, Mid-day meal, etc. would facilitate to ensure in providing nutritionally balanced food to poor people. Policymakers are required to give higher priority by giving incentives to producers, millers and consumers for ensuring the reaching of biofortified rice at the doorsteps of rural population. The role of food industry through value chain is also very crucial to include biofortified crops in their products. To achieve the target of moving from food security to nutritional security, biofortified rice will play a crucial role in coming days.

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Chapter 05

Advanced Technologies for Climate-Smart Breeding

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Abstract

Climate change has a negative influence on agricultural production and product quality, posing a risk to global food and nutritional security. Changing the genetic makeup of crop plants to make them more resilient to the uncertainties of climate change is the most sustainable and farmer-friendly option for addressing the issue. We discuss here the major focus areas of climate-smart breeding, as well as the breeding strategies that can be used effectively to address the challenges of climate change. We focus on advanced breeding technologies in this chapter, including speed breeding, molecular marker-assisted breeding, genomic selection, transgenesis, and genome editing, as well as their practical use in developing climate-resilient crop varieties. Integrating conventional breeding tactics with modern molecular, genomic, and phenomic technologies is required for the development of climate-resilient varieties. Rapid and precise genotype identification using low-cost high-throughput genotyping and precision phenotyping is critical for the effective deployment of climate-smart breeding technologies in product development.

Keywords: Climate-smart varieties, speed breeding, marker-assisted breeding, genomic selection, transgenesis, genome editing

1. Introduction

During the 1980s and 1990s, the Pulpally and Mullankolli panchayats in Kerala's Wayanadu district had one of the richest farming communities in India. Every household had a Mahindra Jeep, and these ordinarily distant settlements had the best road infrastructure. It's all because of the 'Black Gold' (black pepper) they have planted in their fields. However, the situation has shifted dramatically since the early 2000s. The Wayanadu district's black pepper farming has been decimated by climate change, which has resulted in high heat, drought, and the spread of the disease 'quick wilt'. Productivity has dropped to 10%, and black pepper producers have gone bankrupt. According to 2022 estimates, at least 3500 farmers in the Pulpally and Mullankolli panchayats are facing foreclosure under the SARFAESI Act (2002). More than 15,000 farmers in the Wayanadu district are suffering foreclosure under this Act. Farmer families that used to cultivate black pepper are now attempting to migrate to European countries in quest of work. Many women from the two panchayats have already left for domestic employment in Middle East countries. Parents are attempting to sell everything they own to send their children to Europe. Climate change is more than a distant concern; its harmful consequences are being felt in diverse places of the world. The black pepper saga in the Wayanadu region demonstrates how much climate change can affect people's lives and the socio-economic fabric of our society. Climate change would have a generally negative impact on agriculture, with the exception of a few favourable benefits for some crops. The negative consequences of climate change for agriculture include decreased crop yield, uncertainty about the duration, frequency, and intensity of abiotic stresses, changes in pest profiles, reduced food quality, and the appearance of new pests, diseases, and weeds. The scientific community faces a huge task in addressing the challenges posed by climate change in a timely manner. The food and nutritional security, as well as the existence of all living things on Earth, are all dependent on how successfully we can deal with the challenges. Changing the genetic make-up of crop plants, either by conventional plant breeding, transgenesis (also known as genetic engineering), or through genome editing technologies, is regarded as the best and most effective strategy recommended to handle the issues posed by climate change. This chapter provides a brief overview of plant breeding strategies for climate-smart breeding, with special emphasis on advanced technologies.

2. Focus areas of climate-smart breeding

Climate-smart breeding focuses on three key aspects: 1) faster product delivery, 2) enriched products, and 3) products with a wider genetic base. Genetic improvement techniques are variable depending on the goal, with an integration of different approaches being advocated for the practical mitigation of the effects of climate change on agriculture (Figure 1).

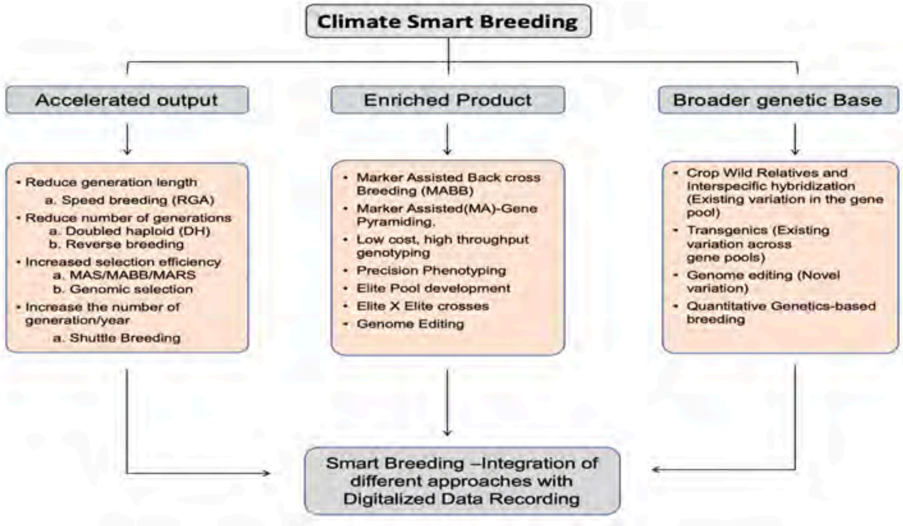

Figure 1. Focus areas and different approaches of climate-smart breeding

2.1. Accelerated product delivery

Varietal development through traditional breeding is dependent on the crop duration and genetic architecture of the target traits. Development of a superior variety takes more than a decade using traditional breeding methods (Breseghello and Coelho, 2013). However, the unpredictable and rapidly changing climate necessitates swift product development and delivery. Conventional breeding tactics must be updated, new strategies must be devised, and traditional breeding strategies must be integrated with modern molecular, genomic, and phenomic technologies to meet the challenges. The strategies proposed to reduce the length of breeding cycles and accelerated product delivery in rice include shuttle breeding (off-season nursery), doubled haploid (DH) technology (Thomas et al., 2003), reverse breeding, use of molecular markers (MAS, MABB, MARS), speed breeding and genomic selection. Due to the inherent disadvantages of some of these technologies, they are used on a limited scale in plant breeding: off-season nurseries are costly, and seed movement across country borders is troublesome due to intellectual property restrictions and the biodiversity act. On the other hand, doubled haploid technology is only feasible in species that has tissue culture system established. In comparison to the *japonica* subspecies, it is more difficult for the *indica* subspecies to establish doubled haploid populations (Grewal et al., 2011).

2.2. Enriched products

Climate change has a negative impact on crop productivity, nutritional quality, and stress resilience, among other things. To address climate change, crop varieties should be enriched for yield-enhancing genes, nutritional quality, and resilience to biotic and abiotic stresses. Marker-assisted backcross breeding (MABB) allows for precise introgression of specific genes in elite genetic backgrounds; introgression of multiple genes for the same trait *viz.,* stress tolerance is done through marker-assisted gene pyramiding; and elite x elite crosses and elite pool development allow for the effective and rapid accumulation of maximum contributing alleles for polygenic traits like yield.

2.3. Broader genetic base

A narrow genetic base and the resulting genetic uniformity predispose cultivars to higher susceptibility to biotic and abiotic stress, and their stability and buffering capacity are reduced under unpredictable abiotic stress circumstances. Inter-specific and inter-generic hybridization, along with techniques like embryo rescue, should be used to exploit crop wild relatives (CWRs) to find novel alleles of reported genes and novel genes for agronomically important traits in the entire genepool of the crop. Transgenic technology could be used to harness existing genetic variation across phyla, whereas site-directed mutagenesis, TILLING, Eco-TILLING, and genome editing technologies could be used to produce novel genetic variations. Precise genome editing technologies like base editing and prime editing could also be used to mimic useful genetic variation in cultivars (Molla et al., 2021).

3. Speed breeding

Initially, Watson et al., (2018) proposed the concept of speed breeding, in which a population's growth time is reduced by using a short-day treatment. However, the term "speed breeding" is now used to refer to all breeding strategies based on the principle of shortening generation lengths, in which accelerated plant growth, early flowering, and seed set are achieved through the use of plant growth hormones or the manipulation of photoperiod, planting density, temperature, soil moisture, soil nutrition, light intensity etc. under controlled or field conditions. When compared to regular field conditions, speed breeding entails growing plants in conducive growth circumstances to enable early flowering and seed set (Ghosh et al., 2018; Alahmad et al., 2018). By growing the plants in a greenhouse or screen house facility and completing numerous generations or cycles in a shorter or faster time, speed breeding is more versatile and speeds physiological development (Sysoeva et al., 2010). In comparison to conventional breeding, speed breeding with the integration of SSD (single seed descent) and modern breeding procedures like genomic selection and genome editing result in faster line development, higher genetic gain, and effective resource usage at a lower cost. Even though rice is a short-day plant that responds to light duration and intensity during its growth and flowering stages, the use of speed breeding or types of speed breeding is quite limited. When Rana et al. (2019) combined speed breeding approaches with a marker-assisted backcrossing procedure, they were able to generate a novel salt-tolerant variety faster. Jamali et al. (2020) presented "speed DUS testing," a speed breeding approach for DUS testing that extended speed breeding's applicability from varietal development to varietal protection.

4. Molecular marker-assisted breeding

Over the last 30 years, the integration of molecular markers for trait selection has resulted in major advances in selection efficiency in varietal development programmes. Plant selection using molecular markers is generally more effective than traditional approaches because it improves accuracy, decreases environmental error, and saves time. The most prevalent method used today to introgress a target gene into a popular variety for trait improvement is marker-assisted backcross breeding (Mackill et al., 2010), and this strategy has been successfully employed in abiotic stress tolerance breeding in rice (Gregorio et al., 2013; Ismail et al., 2013; Sandhu et al., 2017). ICAR-National Rice Research Institute, Cuttack, has developed five varieties by MAS, three for bacterial blight resistance (Improved Lalat, Improved Tapaswini, and CR Dhan 800) and two for abiotic stress tolerance (CR Dhan 801 and CR Dhan 802)

CR Dhan 800: derived from the cross IR81896-B-B-195/2*Swarna-Sub1//IR91659-54-35, CR Dhan 800 was developed by the marker-assisted introgression of bacterial blight resistance genes in the background of the popular variety Swarna. The variety has three BB resistance genes *Xa21, xa13,* and *xa5,* and is reported to be highly effective against bacterial blight in the shallow lowland ecology. The variety has a maturity duration of seed to flowering 115 days and seed to seed 140 days and has short plant stature (85-90 cm). Lemma and palea colour of the variety is slightly lighter in colour than the original parent Swarna, which is brown. The variety is resistant to lodging and shattering, has fertilizer responsiveness, and is suitable for early or late sown conditions. It has medium slender grain, high milling, and head rice recovery, and intermediate amylose content. It has recorded an all-India average yield of 4565 kg/ha.

CR Dhan 801: The variety was developed from the breeding materials of cross IR81896-B-B-195/2*Swarna-Sub1//IR91659-54-35. It is the first climate-smart variety, first of its kind in the entire globe, developed by the institute and released for cultivation in the year 2019. The variety contains *Sub1* gene for submergence tolerance and *qDTY1.1*, *qDTY2.1* and *qDTY3.1* yield QTLs for drought tolerance, which were stacked in the background of the Swarna variety using marker-assisted backcross breeding. Hence the variety is tolerant to extreme conditions of drought and submergence. The variety performs excellently under submergence and drought and the yield is at par with Swarna-Sub1. The genotype is weakly photosensitive with an average maturity duration of 140-145 days. It possesses short bold grain with a test weight of 20.5 g. It is resistant to stem borer (both dead heart and white ear heads), leaf folder and case worm while moderately resistant to bacterial blight and rice tungro virus. CR Dhan 801 has good hulling, milling, and head rice recovery.

CR Dhan 802: The MAS-derived variety CR Dhan 802 was derived from the cross Swarna-Sub1*4 / IR81896-B-B-195, and has Sub1 gene for submergence tolerance and QTLs qDTY1.1, qDTY2.1 and qDTY3.1 for drought tolerance introgressed in the genetic background of the mega variety Swarna. It is a climate-smart variety developed by the institute and released for cultivation in the states of Bihar and Madhya Pradesh in the year 2019. The variety has a duration of 142 days. The grain type is short bold. The variety is tolerant to extreme conditions of drought and submergence. It is resistant to stem borer (both dead heart and white ear heads), leaf folder, plant hopper, and case worm while moderately resistant to bacterial blight, sheath rot, and rice tungro virus.

5. Genomic selection

Genomic selection is a type of marker-assisted selection that makes use of a large number of genetic markers that span the entire genome. GS permits the selection of superior individuals using estimated genomic breeding values that account for the impact of numerous genes regulating a target trait. Genomic selection (GS) was initially developed in the animal system as a variant of marker-assisted selection. Given the method's success in increasing the rate of genetic gain in cattle breeding, it was applied to plant breeding (Meuwissen et al. 2001; Schaeffer 2006; Smith et al. 2008).

GS makes use of genome-wide marker effects to assign genotypic values to members of the population from which they are selected for quantitative trait improvement. GS can be thought of as a modified form of Marker Assisted Selection (MAS), with genome-wide dense DNA markers used to accurately predict genetic values for subsequent selection (Hickey et al. 2017). GS, on the other hand, is better suited for quantitative traits governed by polygenes with modest effects (He et al. 2016). The primary objective of GS is to correlate a training population's phenotype with its genome-wide DNA marker effect and to forecast the genetic worth of future individuals in breeding/test populations (Desta and Ortiz 2014).

The two major steps in the genomic selection are (i) in the 'training population,' the genome-wide linkage disequilibrium (LD) among markers is assessed by using genome-wide DNA markers to create a genotype-phenotype relationship model, and (ii) forecasting genomic estimated breeding values (GEBV) in future candidates of other related populations (the breeding population) based on the model (Meuwissen et al. 2001; Heffner et al. 2009). The accuracy of prediction and predictability of models adapted to diverse crops are critical to the success of GS (Crossa et al. 2017). However, numerous factors influence predictability, including population relatedness, marker density, trait heritability, sample size, and so on (Heslot et al. 2012).

While rice is a model genetic crop, its use by GS to solve many researchable problems is still limited in comparison to maize. Table 1 summarises some of the attempts done to include GS in rice breeding for yield improvement and a few on disease resistance breeding. The majority of GS studies in rice are aimed at increasing the predictive accuracy of various models suited for the enhancement of a few yield and related parameters (Bernardo and Yu 2007; Lorenz 2013; Zhang et al. 2015).

Table 1. Genomic selection studies conducted in rice

Sl. No.	**Target trait**	**Plant material**	**Statistical method**	**Reference**
1	Yield, Tillers, grain number and grain number	240 RILs and 360 derived crosses	LASSO, GBLUP and SSVS	Xu et al. (2014)
2	Plant Height and protein content	Diversity panel of 413 accessions	GBLUP	Guo et al. (2014)

3	Flowering, Plant height, Panicle weight and yield	Synthetic population of size 400	GBLUP, rrBLUP and LASSO	Grenier et al. (2015)
4	8 agronomic traits including yield	110 Asian rice cultivars	GBLUP, RKHS and LASSO	Onogi et al. (2015)
5	Yield and related traits	369 elite breeding lines	GBLUP and RKHS	Spindel et al. (2015)
6	Yield and related traits	Structured diversity panel of 413 accessions	GBLUP	Isidro et al. (2015)
7	Heading dates	174 BILs along with parental lines	EBL and GBLUP	Onogi et al. (2016)
8	8 agronomic traits including grain yield	575 F_1 hybrids	GBLUP	Wang et al. (2017)
9	Grain yield and related traits	575 hybrids generated using NC II design	GBLUP, LASSO, SVM and PLS	Xu et al. (2018)
10	Grain filling ability	Diversity panel of 128 lines	GBLUP, PLS	Yabe et al. (2018)
11	Resistance to rice blast	161 African rice accessions	GBLUP	Huang et al. (2019)
12	Grain yield and plant height	Diversity panel of 280 accessions	GBLUP and RKHS	Bhandari et al. (2019)
13	Arsenic content in flag leaf and cargo grain	Diversity panel of 225 accessions and 95 elite lines	GBLUP and RKHS	Frouin et al. (2019)
14	Yield, Grain weight and grain number	210 F_9 RILs	2D BLUP-HAT	Wang et al. (2020)
15	Yield and related traits	1495 hybrids	GBLUP	Yanru Cui et al. (2020)

RIL-Recombinant inbred line; BIL-Backcross inbred line; NC II- North Carolina mating design II; LASSO- Least Absolute Shrinkage and Selection Operator; GBLUP- genomic best linear unbiased prediction; SSVS-Stochastic search variable selection; rrBLUP- ridge regression best linear unbiased prediction; RKHS-reproducing kernel Hilbert space regression; PLS-partial least-square; 2D BLUP-HAT-two dimensional bivariate BLUP-HAT; SVM- Vector support machine.

6. Transgenesis

All the breeding technologies discussed above allow us to transfer useful genetic elements or genetic regions between closely related species. Those breeding technologies can not be applied in sexually incompatible genotypes. For example, we cannot transfer a beneficial trait of wheat into rice. This limit can be overcome through transgenesis or genetic engineering technology. It allows us to use the entire gene pool of the biosphere. Cross-kingdom transfer of desired genes is possible through this technique. Moreover, transgenesis could shorten the breeding time and overcome the problem of linkage drag. Transgenesis has been used extensively for crop improvement by harnessing the beneficial genes from distantly related species. For example, bacterial genes (encoding CRY proteins) have been transferred to multiple crops for developing insect pest resistance (Ganguly et al., 2014; Tilgam et al., 2021). Although controversial in many countries, genetic engineering has tremendous potential in climate-smart agriculture. Drought-Guard Maize, a transgenic drought-tolerant crop, has been released for cultivation. Drought-Guard Maize has been developed by transferring *cspB* (cold shock protein B) gene from *Bacillus subtilis* (Castiglioni et al., 2008). Drought-Tolerant maize exhibited more yield under Drought-Stressed conditions without any yield penalty in favourable environments (Adee et al., 2016). Similarly, Argentina has approved the cultivation of HB4 drought-tolerant wheat in 2022. A sunflower transcription factor gene, *hahb-4*, has been transferred to develop HB4 wheat (Gonzalez et al., 2019). Although many genes have been proved to be useful in improving drought tolerance in plants, very few have been commercialized for different reasons. *DREB1A* and *DREB1B* genes from rice and wheat improved drought and salinity tolerance in transgenic rice plants (Datta et al., 2012).

Methane is a greenhouse gas, responsible for global warming. Rice cultivation is one of the largest sources of anthropogenic methane emissions. Rice root exudates provide ideal nutrition for methanogens in the rice field. Transgenic rice with barley *SUSIBA2* gene reduced methane emission and the number of rhizospheric methanogens by allocating more photosynthates to aboveground biomass than roots (Su et al., 2015). Another most widely deployed transgenic trait is herbicide tolerance. Cultivation of herbicide-tolerant crops reduces tilling and helps in soil carbon sequestration, thereby reducing the CO_2 emission in the air.

In genetic engineering, the desired gene is isolated from an organism, an expression cassette (promoter-gene-terminator) is constructed and genetically transformed into a target crop (Karmakar et al., 2019). To apply transgenic technology to any crop, an established genetic transformation and regeneration protocol is required. However, many genotypes are recalcitrant and difficult to genetically transform and regenerate through tissue culture. However, a gene could be transferred stably to a genotype that is easy to transform and subsequently transferred to a desired genotype (recalcitrant in tissue culture) through marker-assisted breeding.

7. Genome editing

Genome editing is the most recent and advanced breeding technology. This technology has the unprecedented ability to create a new genetic variation at target genetic loci with high accuracy. Within a very short span of time, genome editing technology has been adopted and deployed in a diverse arena of plant breeding, including climate-smart breeding (Gao, 2021). Zinc Finger Nuclease (ZFN), Transcription activator-like effector nucleases (TALEN), and CRISPR-Cas are the three available genome editing tools, among which CRISPR-Cas has gained rapid popularity due to its versatility and ease of use. ZFN, TALEN, and CRISPR-Cas tools can create a targeted double-strand break in the genome. The creation of genomic DSB induces cellular repair pathways and the formation of random insertions or deletions (indels). These indels are novel genetic variation that can be artificially created with genome editing tools. If indels are generated in a gene coding sequence, the gene function is often disrupted. Therefore, genome editing tools greatly facilitate us to disrupt undesired genes for crop improvement.

In CRISPR-Cas, with the help of a small guide RNA and a Cas nuclease, one can generate genetic variation precisely at a desired location of the crop genome (Molla et al., 2020a). Although Cas9-induced indels can be predicted (Molla et al., 2022), the formation of indels is uncontrollable. Therefore, for generating precise indels, conventional ZFN, TALEN, and CRISPR-Cas tools are inefficient. Recently developed base editing tools can perform targeted swapping of one nucleotide with another in the genome (Molla and Yang, 2019; Molla et al., 2020b; Molla et al., 2020c). Prime editing technology enables us to install precisely small insertion, deletion, substitution, and a combination thereof in the genome (Molla et al., 2021). Conventional ZFN, TALEN, CRISPR-Cas along with base editors and prime editors empowered us to perform innumerable types of manipulations in crop genome for climate-smart breeding.

Remarkably, the fruit of genome editing technologies has been realized very rapidly in the form of released crop varieties. A TALEN-facilitated genome-edited soybean has been commercialized in the USA, while CRISPR-Cas9-edited tomato has been recently marketed in Japan. The power of these technologies is being harnessed for breeding climate-resilient crop varieties all over the world. For example, CRISPR-Cas9 generated variants of the ARGOS8 gene enhanced maize yield under drought conditions (Shi et al., 2017). Drought and salt tolerance of rice plants has been enhanced through the editing of the *DST* gene (Kumar et al. 2020). CRISPR-Cas9-mediated knock-out of the *SlAGL6* gene has increased the thermo-tolerance of tomato plants (Klap et al., 2017). Base editing and prime editing tools made it easier to breed non-transgenic herbicide-tolerant crop varieties, which would greatly help us to mitigate CO_2 emission through reduced tilling (Molla et al., 2021). Wild crop relatives have many desirable traits including abiotic and biotic stress tolerance. However, transferring them into cultivars is tedious and many times impossible. Genome editing assisted rapid de novo domestication can facilitate in generating new crop varieties with desired traits removing the unwanted characters (Zsögön et al., 2018). Overall, genome editing technologies provide us with excellent opportunities to rapidly breed crop varieties suitable for a changing climate.

8. Conclusion

All smart breeding technologies rely on successful exploitation/deployment of genetic variation (natural/novel) and need to be easy and cost-effective for rapid adoption. Rapid and precise identification of superior lines, both at the phenotypic and genotypic levels, and rapid generation development are the keys to climate-smart breeding. Integration of genome editing and speed breeding with other technologies will increase the breeding pace like never before. As per the latest IPCC report, India would be one of the worst-hit countries due to climate change, and Indian agriculture would be negatively impacted (Chaturvedi 2022). Rapid deployment of the available technologies could help us to reduce the negative impact of climate change on agriculture.

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Chapter 06

Cataloguing of rice varieties of NRRI suitable for different abiotic stress-prone ecologies

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Abstract

Rice is grown on over 156 million hectares of arable land globally, with Asia generating 90% of the world's rice production. Most people consume more than half of their daily calories from rice, making it an important part of their diets. Rice production is most affected by abiotic stresses like salinity, drought, flash floods, and submergence. The stress causes a significant yield loss across wide areas. Abiotic stresses impair normal physiological and biochemical regulations in plant development and growth, as a result, crop growth and productivity decrease significantly. Drought, salt, low temperatures, and submergence are the key abiotic stressors that have a 70 percent detrimental impact on the agricultural crop. To reduce the adverse impact of abiotic stress on rice crop, various strategies have been developed, however, the best possible solution is through plant breeding approach. The identification and development of stress-tolerant rice genotypes is an important way to minimise the loss from abiotic stresses. Stress tolerant varieties thrive well under adverse conditions and cope with the situation for survivability, and have the mechanism to sustain higher yield than the non-stress varieties. The intensity and duration of abiotic stresses are unpredictable and sometimes result in 100% loss in crops production. Under these situations, the adoption of high yield stress tolerance varieties is the proven technology to cope with the stress for yield sustainability.

1. Introduction

Rice is an annual crop cultivated in a wide range of ecology, where water depth up to 2-3 m in general or may be more. In some areas of Kerela the crop is even grown below the sea level and in some parts of Jammu and Kashmir it is grown 2000 m above sea level (Pathak et al., 2018). Rice is adapted to wide variations in rainfall, variations in soils, agro-climatic situations, and seasonal also, which leads to the development of thousands of varieties of rice suitable for various ecologies. The crop is grown mostly during the wet season or rainy season and in some parts of India, it is also grown in the rabi season. In various ecologies of rice, abiotic stresses such as drought, submergence, stagnant flooding, coastal and inland salinity, alkalinity, acidity are common.

The anticipated yield of irrigated rice is to fall by 7% by 2050 as a result of climate change, but rainfed rice yields are expected to fall relatively less (<2.5%) by 2050 (Kumar, 2017). For rainfed lowland (46 Mha) and highland (10 Mha) rice ecologies in Asia, drought stress is the major limiting factor (Pandey et al., 2007, Anandan et al., 2021; Beena et al., 2021). Due to the sea levels rise, soluble salts dissolved underwater are brought to the surface, resulting in an increase in soil salinity in coastal regions and irrigated plains. Flash floods induce severe hypoxia, reduced photosynthesis, and increased mortality in rice, despite the plant's adaptation to moist conditions (Ramakrishanayya et al., 1999). India, Bangladesh, Myanmar, and Thailand are among the countries in South and Southeast Asia with more than 40 million hectares of rain-fed lowland rice cultivation are severely damaged by the unpredicted occurrence of flash floods (Sarkar et al., 2006).

Unseasonal rainfall, uneven distribution of rainfall, decreasing groundwater level, and unavailability of irrigation create drought during the cropping period (Anandan et al., 2021; Beena et al., 2021). Climate change resulting in a rise in sea level, increases the soil salinity in coastal areas, and poor drainage leading to excessive water deposition leading to flooding stress in low-lying areas. Besides, the rise in the air temperature and low light in eastern India, is also now priorities. The damage caused by these stresses can be effectively addressed through genetic solution, by developing and adopting the stress-tolerant varieties for these ecologies. Rice is mainly cultivated under four major ecosystems (i) upland (ii) irrigated, (iii) lowland and (iv) flood-prone. However, there are other ecologies with less area under cultivation which faces multiple abiotic stresses viz., coastal saline, deep-water etc.This chapter mostly focuses on the varieties suitable for ecologies prone to abiotic stress during the cropping period. Only those varieties are listed in this chapter that were released in the last 10 years and most of them are under the seed chain.

2. Upland ecology

Rice in upland ecology is grown under rainfed conditions during the rainy seasons. The upland rice area covers 9% in Asia (Nascente, 2019). In India, the rainfed upland rice area is ~6.0 Mha (13.5% of the total area). The upland areas are largely situated in eastern zone states like West Bengal, Bihar, Chhattisgarh, Jharkhand, Eastern Uttar Pradesh, Madhya Pradesh, Assam, Odisha, and North East Hill Region. In this ecology, rice is usually grown on level or sloping, unbunded fields. The rainfed upland ecosystem is drought-prone due to limited water availability. Eastern India has one of the world's largest drought-prone ecologies among the major rainfed rice-cultivating zones. (Dar et al., 2020). Besides, nitrogen management is critical that has a significant role in rice productivity in upland ecology. The low water availability favours weed growth in the upland condition which imposes a high cost on the cultivation. To fill the local requirement for rice, rainfed upland rice production is a good alternative. The suitable varieties for this ecology are listed in table 1.

Table 1. Rice varieties suitable for upland ecology

Variety	**Year of release**	**Released for**	**Duration**	**Grain Type**	**Yield (t/ha)**	**Reaction to diseases and pests and special characters**
Satyabhama (CR Dhan 100)	2012	Odisha	110	Medium Slender	2.3-4.7	100-105 cm, Resistance- Leaf Blast, Rice Tungro Virus, Gundhi Bug, Stem Borer, Leaf Folder, White Moth; Moderately Resistance-White Back Plant Hopper,Gull Midge
CR Dhan 101 (Ankit)	2014	Odisha	110	Medium Slender	3.98	100cm, Long Bold Moderately Resistence-Neck Blast, Brown Spot Sheath Rot, Stem Borer, Leaf Folder, Green Leaf Hopper
Gangavati Ageti	2017	Karnataka	85	Long Slender	3.5	Resistant to Brown spot & moderately resistant to leaf blast. Resistant Gall Midge-1, Stem borer & Moderately resistant to Gall Midge Bio.4 & 5 and Leaf folder.
Purna	2017	Gujarat	90	Short Bold	3.5	Moderately resistant to leaf blast and brown spot. Moderately resistant to stem borer and leaf folder.Tolerant to drought.
Santha Bhima (CR Dhan 102)	2020	Odisha	115	Long Slender	3.9	Moderately resistant to leaf blast, rice tungro disease, stem borer, leaf folder and whorl maggot

3. Aerobic rice

Aerobic rice is a cultivation practice, the crop is grown by dry or wet direct seeding in un-flooded and non-puddle field conditions or saturated. Aerobic rice is like upland rice except, in aerobic rice, assured irrigation for the crop is required. In general, aerobic cultivation of rice is more water-efficient, and water used in aerobic rice is around 60% less than other irrigated lowland rice. Aerobic rice has a 1.8-fold greater water productivity and two-fold better net returns on water consumption (Wang et al., 2002; Kumar et al., 2016). In the area where water is limited, but assured irrigation can be made, aerobic cultivation is preferred. This ecology is non-flooded, non-puddled, dry direct-seeded rice with a target to achieve maximum yield with less water. Varieties grown in aerobic rice may face drought stress because of less irrigation, however, recommended varieties are adopted in such situations for yield maximization. Just like the upland rice nitrogen management in aerobic rice is also much critical. The methane emission through decomposition of organic is approximate 50% less hence, this technology is environmentally friendly and safe. (Vial, 2007). Aerobic rice has the following advantages: it saves labour and water, is cost-effective, environmentally friendly, and minimizes pollution, has high nitrogen use efficiency, low cost of production, and improves soil health (Kumar et al., 2016). The suitable varieties for this ecology are listed in table 2 The suitable varieties for this ecology are listed in table 1.

Table 2. Rice varieties suitable for Aerobic ecology

Variety	**Year of release**	**Released for**	**Duration**	**Grain Type**	**Yield (t/ha)**	**Reaction to diseases and pests and spl characters**
Pyari (CR Dhan 200)	2012	Odisha	115-120	Short Bold	4.5	Moderately Resistance-Blast, Neck Blast, Brown Spot, Stem Borer, Gull Midge, and Leaf Folder
CR Dhan 201	2014	Chhattisgarh and Bihar	118	Long Slender	3.8-4.0	Moderately Resistance-Sheath Rot, Stem Borer, Leaf Folder, White Moth
CR Dhan 202	2014	Jharkhand and Odisha	115	Long Bold	3.7-4.5	Moderately Resistance-Brown Spot, Sheath Rot, Stem Borer, Leaf Folder, White Moth

CR Dhan 204	2014	Jharkhand and Tamil Nadu	120	Long Bold	4.8-5.6	Moderately Resistance -Leaf Blast, Neck Blast, Brown Spot, Sheath Rot, Stem Borer, Leaf Folder, White Moth, It has moderate resistance to leaf blast and good grain quality characteristics
CR Dhan 205 (IET 22737)	2014	Tamil Nadu, Gujarat, Odisha, Madya Pradesh, Punjab	110	SB	3.7-4.5	Leaf Blast, Brown Spot, Sheath Rot, Stem Borer, Leaf Folder,
CR Dhan 203 (Sachala)	2014	Odisha	110	LS	4.05	110 cm, Moderately Resistance- Leaf Blast, Brown Spot, Sheath Rot, Stem Borer, Leaf Folder
CR Dhan 206 (Gopinath)	2014	Odisha	115	SB	3.95	105 cm, Moderately Resistance -Leaf Blast, Brown Spot, Sheath Rot, Stem Borer, Leaf Folder
CR Dhan 207 (Srimati)	2016	Odisha	110-115	MS	3.7	95-100 cm, Moderately Resistance - Blast, Neck Blast, Brown Spot, Sheath Rot, Stem Borer, Leaf Folder, Green Leaf Hopper, Gull Midge-B1&4,
CR Dhan 209 (Priya)	2016	Odisha	112-115	LS	4.07	95-100 cm, Moderately Resistance- Blast, Neck Blast, Brown Spot, Rice Tungro Virus, Stem Borer, Leaf Folder, Green Leaf Hopper, White Back Plant Hopper
Sarumina (CR Dhan 210)	2020	Odisha	110-115	LS	7.8	Moderately resistant to leaf blast, neck blast, brown spot, sheath rot, stem borer, leaf folder and green leaf hopper

4. Rainfed shall lowland

The rainfed lowland ecosystem accounts for 37% of the total rice cultivated area (43 mha) in our country. Nearly 92% of all of the country's rain-fed lowland areas are found in the eastern part. There are four distinct types of lowland rice ecosystems based on the depth and period of water stagnation: rainfed shallow lowland, semi-deep, deep, and very deep water. Drought and flash floods are common in this rain-fed shallow lowland. Water accumulation ranges from 0 to 30 centimeters in rainfed shallow lowland ecology (Pradhan et al., 2021). Due to harsh stress, such as drought and flood, this ecology's productivity and yield are extremely low. However, despite the abundance of water and stagnant water in the ecosystem, drought spells can also occur. Submergence conditions of more than ten days are frequent in most low-land rice fields during the cropping season. The variety of this ecology bred to a higher height than irrigated varieties due to water stagnation. Lodging is a serious concern in this ecology because of frequent strong winds, and untimely rains during grain maturity, which causes severe crop loss owing to lodging. To minimise environmental impact on grain yield, sufficient culm strength is required in the plant. Improving the productivity of rainfed lowland ecosystems is a potential alternative for raising the overall rice production of the country. This ecosystem has a difficult position throughout the cropping season, both in terms of the type of stress and the length of time it is exposed to it. Anaerobic germination is also one important trait to be included in the cultivars for this ecology. The suitable varieties for this rainfed shallow lowland and shallow lowland are listed in table 3.

Table 3. Rice varieties suitable for Rainfed Shallow lowland ecology

Variety	**Year of release**	**Released for**	**Duration**	**Grain Type**	**Yield (t/ha)**	**Reaction to diseases and pests and special characters**
Rainfed Shallow lowland ecology						
CR Dhan 407	2014	CVRC(Odisha and West Bengal)	150	LB	5.0	Moderately Resistance to Leaf Blast, Neck Blast;
CR Dhan 801	2019	CVRC (AP, Telengana, Odisha, UP and WB)	140	SB	6.3	For submergence and drought-prone areas
CR Dhan 413	2021	SVRC (Odisha)	145	SB	4.2	It is resistant to Brown Plant Hopper, White Back Plant Hopper, stem borer (dead heart) & moderate resistance to white ear head, leaf, plant hopper, leaf folder and case worm

CR Dhan 803	2021	SVRC (Odisha)	150	SB	6.2	resistant to stem borer (dead heart) and BPH and moderately resistant to white ear head attack, White Back Plant Hopper, leaf folder, plant hopper, and case worm. The variety was moderately resistant to neck blast and rice tungro virus
CR Sugandh Dhan 910	2016	Odisha	142-145	MS	4.38	101cm, Moderately Resistance to Blast, Neck Blast, Sheath Rot, Rice Tungro Virus, Stem Borer, Leaf Folder, White Back Plant Hopper
CR Dhan 410 (Mahamani)	2020	Odisha	155-160	LS	7.0	Moderately resistant to stem borer, leaf folder, neck blast, bacterial blight, sheath rot and brown spot
CR Dhan 411	2021	SVRC (Odisha)	140	SB	5.6	Moderate tolerance to leaf blast, neck blast, brown spot, Rice Tungro Disease and Bacterial Leaf Blight, moderately resistant against stem borer. Biofortified 'high protein Swarna' with 10% protein content
CR Dhan 408 (Chaka Akhi)	2014	Odisha	165 PS	LB	4.8	135cm, Moderately Resistance to Leaf Blast, Neck Blast, Bacterial Leaf Blight, Sheath Rot, Stem Borer, Leaf Folder, White Back Plant Hopper
CR Dhan 800	2016	Odisha	140	MS	5.75	90cm, Moderately Resistance to Bacterial Leaf Blight, Sheath Blight,

CR Dhan 802 (Subhas)	2019	CVRC (Bihar, Madhya Pradesh)	142	SB	6.5	Submergence and drought tolerant, It is resistant to stem borer (both dead heart and white ear heads), leaf folder, plant hopper and case worm while moderately resistant to bacterial blight, sheath rot and rice tungro virus.
Sumit (CR Dhan 404)	2012	Odisha	145	LB	5.2	108-115 cm, Resistance to Leaf Blast, Stem Borer, Leaf Folder
Poorna Bhog (CR Basna Dhan 902)	2012	Odisha	140	LS	4.5-5.0	100 cm, Resistance to Neck Blast, Gull Midge and Moderately Resistance to Sheath Rot and Stem Borer.
CR Dhan 702	2021	SVRC (Odisha)	140-145	LS	7.5-8.0	Moderately resistant to leaf blast, neck blast and resistant to false smut; and Moderately resistant to Gull midge
CR Dhan 703	2021	SVRC (Odisha)	165 (Boro) & 140-145 (Irrigated)	LS	7.5-8.0	Moderate Resistant to leaf Bacterial Leaf Blight, Rice Tungro Disease and resistant to False smut; and Moderate Resistant to Gull midge

5. Waterlogged ecology

The saturation of soil with water, either temporarily or permanently, is known as waterlogging. Waterlogging affects ~3.0 million hectares of rice land in our country, especially in the coastline region. The waterlogged environment is less receptive to better management because of the repeated submergence owing to flash floods and waterlogging. Water accumulates to roughly 25-30 cm in these areas for a significant portion of the crop growing season. In eastern Uttar Pradesh, Bihar, West Bengal, Assam, and Odisha, the crop is produced in shallow (up to 30 cm), semi-deep (30-100 cm), and deep-water (>100 cm) ecosystems. Waterlogging during the early phases of crop development inhibits tillering and increases plant mortality. In waterlogged areas, Poor drainage causes harmful compounds to accumulate, such as iron toxicity and sulphide damage (Pradhan et al., 2021 a).

Flooding stress causes substantial crop losses because it creates an anaerobic environment. During the *Kharif* season, flash flooding wreaks issues on rice-growing regions in South and Southeast Asia, including India, Thailand, Bangladesh, Indonesia, Vietnam, and Myanmar (Sarkar et al, 2006). Around 22 million hectares of rainfed lowland areas in South and Southeast Asia have been flooded, along with 6.2 million hectares of the rice area in India (Azarin et al, 2017; Dar et al, 2017). Out of 22 million hectares of rainfed lowland, only 15 million hectares are affected by short-term flash floods. Flood-prone areas account for approximately 7% of world rice acreage and provide 4% of global rice production (Yang et al, 2017). Semi-deep-water ecology consists of lowland regions with up to 75 cm of standing water, remain waterlogged for roughly a month. In the deepwater ecology the water level rises to one meter and remain for more than a month. In case of floating rice or very deep-water ecology, water depth is more than one meter and remains for a month. The suitable varieties for this ecology are listed in table 4.

Rice genotypes with fast elongation capability are ideal for deep water and partially deep-water situations, whereas cultivars with slower elongation development are preferred for cultivation in areas impacted by flash floods (Sarkar and Bhattacharjee, 2011; Vergara et al, 2014).

Table 4. Rice varieties suitable for Deep Water ecology

Variety	Year of release	Released for	Duration	Grain Type	Yield (t/ ha)	Reaction to diseases and pests and special characters
CR Dhan 500	2011	CVRC (Odisha, UP)	160	MS	3.5	Moderately Resistance to Blast, Neck Blast, Brown Spot, Gull Midge 1&5, Stem Borer, Resistance to Leaf Folder
Jalamani (CR Dhan 503)	2012	Odisha	160	MS	4.6	Moderately Resistance to Leaf Folder, Green Leaf Hopper, Blast, Neck Blast, Brown Spot, Gull Midge, Stem Borer
Jayanti Dhan (CR Dhan 502)	2012	Odisha	160	MS	4.6	Moderately Resistance to Blast, Neck Blast, Sheath Blight, Sheath Rot, Rice Tungro Virus and Gull Midge 1; Resistance to Stem Borer, Leaf Folder

CR Dhan 505	2014	CVRC (Odisha and Assam)	162	MS	4.5	blast, neck blast, sheath rot, sheath blight and rice tungro virus, stem borer (both dead heart and white ear heads), leaf folder, whorl maggotm, submergence tolerance, elongation ability.
CR Dhan 507 (Prasant)	2016	Odisha	160	MS	4.75	140-155cm, Moderately Resistance to Neck Blast, Brown Spot, Sheath Blight, Sheath Rot, Stem Borer, Leaf Folder, White Moth
CR Dhan 508	2017	Odisha, West Bengal, Assam	187	LB	4.4	Moderately Resistance to sheath blight, brown spot and sheath rot.

6. Coastal saline ecology or salinity

Approximately 6.74 million hectares (ha) of the country are salt-affected, and an additional 10% of the land is salinized each year, implying that by 2050, over half of the country's arable land would be salt-affected. Saline soils cover 44% of the land in 12 states and one union territory, whereas sodic soils cover 47% of the land in 11 states. Rice is more sensitive to salinity stress than other cereals. Rice is relatively tolerant during germination, tillering (vegetative growth), and maturity stages (Wang et al., 2010). The highest sensitivity has been reported during the early seedling and reproductive stages (Zeng and Shannon, 2000).

Rice development stages may be divided into two categories: vegetative and reproductive. The vegetative phase can be further separated into early and late stages. Rice germination reaction to salt has been studied extensively, and it has been discovered that rice is less susceptible during germination but becomes sensitive during emergence and seedling development (El Mokhtar et al., 2015). Salinity, on the other hand, is said to slow germination and reduce total germination percentage (Vibhuti et al., 2015). Coarse sandy to fine loamy textures, mild calcareous composition, moderately salty to alkaline pH, and salinity range from neutral to alkaline are all characteristics of coastal saline soils. All of the nutrients in these soils are in limited supply: nitrogen, phosphorous, zinc, and organic matter. Traditional coastal rice landraces are resistant to salinity and subnergence, even though they provide only marginal yields. Some of the most popular landraces include Vikas, Korgut, Sathi, Picha neelu, Kuthiru, Kalundai samba, Bhurarata, Karekagga, and Nona Bokra.

The soil's salinity changes seasonally. Between January and May, it reaches its peak and then drops off as the monsoon season approaches. Subsurface infiltration of seawater in subsoils is made worse by the backwash from the sea, tidal waves, and wind-borne salts. The suitable varieties for this ecology are listed in table 5.

Table 5. Rice varieties suitable for Coastal Saline ecology

Variety	Year of release	Released for	Duration	Grain Type	Yield (t/ha)	Reaction to diseases and pests and special characters
CR Dhan 412 (Luna Ambiki)	2021	SVRC (Odisha)	140	MS	4.3	In Odisha, it is tolerant to Bacterial Leaf Blight, moderately tolerant to sheath rot, moderately resistant to stem borer and resistant to leaf folder. Tolerant to coastal salinity and moderately tolerant to stagnant flooding
Luna Barial (CR Dhan 406)	2012	Odisha	150	SB	4.1	120 cm, Moderately Resistance to Blast, Leaf Folder and Sheath Blight
Luna Sankhi (CR Dhan 405)	2012	Odisha	110	MS	4.6	Moderately Resistance to Blast and Sheath Blight

7. Boro rice

Boro rice is planted from November to May on waterlogged, low-lying, or medium-lying soils that receive irrigation. This type of rice has traditionally been grown in Bangladesh's river basin deltas and Eastern India, especially Eastern Uttar Pradesh, Bihar, West Bengal, and Assam. Throughout the monsoon season, water accumulates in these regions and is not drained out during the winter, thus keeping substantial moisture in Chaur-lands/Tal-lands. This strategy is becoming popular, even in non-traditional locations where irrigation is available. Farmers are unable to cultivate crops during the rabi season since they would not be able to cultivate otherwise. Boro rice systems take advantage of the moisture that remains after the *Kharif* rice harvest is completed (Lal et al., 2013, Pradhan et al., 2021b).

Photo-insensitive Boro rice varieties are transplanted and cultivated on supplementary irrigation during the winter season. Deep-water areas of eastern India, where *Kharif* rice harvests have traditionally been low, are recognized for their high yields of 5-6 t/ha from Boro rice. As an irrigated crop, water management of boro rice has to be more organized than other crops. The crop very well responds to higher fertilizer doses, ensuring greater yieldThe cold at the early stage is the major abiotic stress, the varieties recommended for this ecology should have cold tolerance ability at the early seedling stages (Singh, 2002; Pradhan et al., 2021b). The suitable varieties for this ecology are listed in table 6.

Table 6. Rice varieties suitable for Boro ecology

Variety	Year of release	Released for	Duration	Grain Type	Yield (t/ha)	Reaction to diseases and pests and special characters
CR Dhan 602	2020	CVRC (Assam and Tripura)	155 (Boro) 125 (Non-boro)	LS	6.0	Moderately resistant to leaf blast,
CR Dhan 703	2021	SVRC (Odisha)	165 (Boro) & 140-145 (Irrigated)	LS	7.5-8.0	Moderate Resistant to leaf Bacterial Leaf Blight, Rice Tungro Disease and resistant to False smut; and Moderate Resistant to Gal midge

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Chapter 07

Prospects of Direct Seeded Rice under Changing Rice Environment – Present Scenario and Future Needs

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Abstract

Direct seeded rice (DSR) is the key climate resilient rice production technology. It not only saves energy, labour, water, and nutrients but at the same time protect soil, biodiversity, and climate change. In this chapter we have discussed in detail the major advantages and limitations of DSR. The constraints and risk associated with these technologies also elaborated. Subsequently the types of DSR and different management practices followed are explained with examples. The pest management including weed, insect and disease are presented in separate sections. The major problem of DSR associated with management are presented elaborately with control measures including agronomic, chemical measures.

Keywords

Direct seeded rice, weed management, nutrient and water management, pest control.

1. Introduction

Rice (*Oryza sativa* L.), the important cereal crop of the world, is the staple food of more than 4 billion people (56% of the world population) and is occupied 10% of the total crop lands (about 166 million hectare). Globally the crop is cultivated in by 144 million farm families (25% of total farmers) and livelihood to 400 million rural poor (40%). Asia is the leading producer and consumer of rice contributing about 90% of the global rice production (Bandumula, 2018). It is the most important food crop of India which feeds about 0.8 billion people in the country (65% of total population) and contributes 40% of total food grain production which plays a vital role in food and livelihood security for almost every household in India. It is the livelihood to 150 million rural poor (40% of poor) with annual value of US$ 53 billion (17% of crop value). The crop is grown in about 43.8 million ha with a production of 118.4 million tonnes and average productivity of 2.7 t ha^{-1} in the year 2019-20 (Annual Report 2020-21, Department of Agriculture, Cooperation & Farmers' Welfare, Ministry of Agriculture & Farmers' Welfare Government of India). The projected demand for rice by 2050 is estimated to be 197.40 million tonnes for a population of 1.65 billion which is almost 80% higher than the current demand (Joshi, 2021). Simultaneously agriculture sector is facing two challenges; in one hand, the demand for the cereal crops is increasing for the ever-increasing population and on the other hand, the input resources vital for agriculture viz. water, labour etc. are decreasing. It would be a great challenge to meet the ever-increasing rice demand in a sustainable way. The rice-based cropping systems are in risk with respect to productivity and sustainability due to various causes viz. (1) non-judicious use of inputs like fertilizer, water, labour etc.; (2) resources like water and labour are becoming increasingly scarce; (3) climate change; (4) rising fuel prices and increasing energy crisis; (5) increasing cost of cultivation; and (6) evolving socio-economic changes like urbanization, migration of agricultural labourers from village to urban areas for doing non-agricultural work, worries regarding pollution by farming (Ladha et al. 2009)

The most common rice establishment method in India is puddled transplanted rice (PTR) where the crop is traditionally grown by transplanting of 4–6-week-old seedlings into puddled fields. Puddling refers to the ploughing of field under ponded water condition which is done in rice culture in order to reduce the soil permeability, control the weeds, facilitate transplanting of rice seedlings and to reduce the deep percolation loss of water to create and maintain an anaerobic condition which increase the availability of different nutrients like iron, zinc and phosphorus essential for the growth of rice crop. However, it is evident from many findings that puddling, and transplanting are the operations which require about 30% of the total water used (1,400-1,800 mm) in rice cultivation (Kannan, 2016), which is increasingly becoming a scarce resource. The crop yearly receives 200 km^3 irrigation water (29% of total water) while the estimates indicate that freshwater share supplied for agriculture is likely to decline in near future under changing climate scenario. Inefficient irrigation systems and larger reliance on groundwater have declined the water tables by 0.1–1.0 m per year in Indo-Gangetic plains, which has led to higher costs of pumping from deep aquifers provoking the energy crisis (Bhatt et al. 2021). Moreover, continued puddling year after year has led to deterioration in soil physical properties of the land through structural breakdown of soil aggregates and capillary pores, and clay dispersion (Tripathi et al. 2007). Puddling forms a compacted layer (plough pan) that restricts deep percolation of water causing a temporary water logging condition which may be a requirement for rice crop, but it causes problem for root penetration and growth of the subsequent crops after harvest of rice (Islam et al. 2014). Along with growing concern of water scarcity, puddling is also energy intensive operation that mainly depends on petroleum fuel causing environmental pollution which is also going to be scarce resource in future. Transplanting operations are usually performed by manual labourer, and now a days labour scarcity is becoming a serious concern for in time transplanting of rice. Thus, the PTR is water, labour and energy intensive agriculture practices, which is adversely affecting the environment. Therefore, a key concern is to bring down the water requirement for rice cultivation.

In this context, presently the major issue is development of alternate technology of rice crop establishment that can avoid puddling and transplanting operations without yield penalty. Direct seeded rice (DSR) technology may serve as alternative which is water, labour and energy efficient and can be adopted where necessity arises. Direct seeding of rice refers to the process of establishing the crop directly from seeds, rather than uprooting the 4-6 weeks aged seedlings from nursery and transplanting them in the main field (Farooq et al. 2011). This technique avoids soil puddling, nursery raising and transplanting without the need of continuous submergence thus reduces the overall water and energy demand and proves to be more economic than PTR. It is therefore more pertinent to follow DSR technique for rice cultivation instead of the conventional TPR in water scarce areas.

Earlier to the 1950s, direct seeding of rice was the most common establishment method in rice culture, however it was eventually replaced by puddled transplanting culture as labour availability was not a big concern till 1980s (Rao et al. 2007). The area under DSR is now increasing during the last two decades owing to its effectiveness with respect to production and profitability to compensate the production cost. DSR system has been being practiced with modifications in different operations like tillage, land preparation, crop establishment technique and cultural operations in order to suit the site-specific situations but have not been so popular among farmers in spite of its well-known proved benefits over PTR (Farooq et al. 2008). In South Asia, DSR has been adopted in ranges of land and regions including medium-deep- and deep-water rice ecologies of the eastern Gangetic plains of India and Bangladesh, and on terraced and sloping lands in the northeast and north-western Himalayan region and the western Ghats along the west coast of India. In Asia, dry seeding is widely practiced in rainfed lowlands, uplands, and flood-prone areas, whereas wet seeding is mainly done in irrigated areas. Direct seeding in saturated soil has been widely adopted in southern Brazil, Chile, Venezuela, Cuba, some Caribbean countries, and in certain areas of Colombia. The area of DSR in India, Pakistan, and Bangladesh is 14.2 million hectares of the total rice area of 55.3 million hectares. Presently, in South Asia 26% of the total rice area has been occupied by DSR. Therefore, DSR has a vast scope to be popular among farmers mitigating and addressing the above cited problems and opportunities.

2. Benefits associated with direct seeded rice

DSR has numerous advantages over PTR. Besides higher economic returns, faster crop growth, earlier and easier crop establishment, less labour and water requirement, it is also conducive to introduction of mechanized cultivation with minimal tillage (Khade et al. 1993). Generally, DSR establishes earlier than PTR as there are no growth delays due to transplanting shock and injury, which hastens physiological maturity and reduces vulnerability to late-season drought thus leading to shorter crop duration (Farooq et al. 2006a, b) and 7–10 days earlier maturity with less methane emissions. Dry seeding of rice on flat bed or raised beds which gets saturated bed on latter stage needs less amount of water as it avoids puddling thus reducing the overall water demand. Succeeding crop can be grown comfortably as the problems arising due to the presence of hard/ plough pan does not exist.

2.1 Major advantages of DSR

1. It saves labour 0-46% and 4-60% in wet-DSR and dry-DSR respectively.
2. It decreases the drudgery by abolishing transplanting operation in rice culture.
3. It reduces irrigation water loss through percolation due to fewer soil cracks.
4. It saves water ranging from 12% to 35% depending on type of DSR.
5. Adoption of direct seeding reduces the methane emissions (6–92% depending on types of DSR and water management)
6. It reduces the production cost i.e., 2-16% and 6-32% in wet and dry DSR respectively.
7. It allows farmers to save 7-14 days of time in crop cycle harvesting the DSR earlier than PTR so that they can grow the subsequent crop timely (Kumar and Ladha, 2011).

2.2 Risk associated with DSR

Despite several benefits associated with DSR, the yields have been found variable across the regions, especially in those areas where dry seeding combined with reduced/zero tillage due to (1) uneven and poor crop stand, (2) poor weed control, (3) higher spikelet sterility, (4) crop lodging, and (5) poor knowledge of water and nutrient management. The rice varieties currently cultivated under DSR are primarily selected and bred for PTR. Under normal practice of direct seeding, the productivity of DSR is often reported to be low, mainly due to poor crop establishment, inadequate use of nutrient inputs, inefficient water management, and the problems associated with weed control. Weed infestation is one of the major biotic constraints for wider adoption of DSR among farmers (Rao et al. 2007). Generally, in DSR, from the beginning the crop and weed germinate and grow simultaneously where weeds are generally more competitive than crop. Presently, the proven technology for direct seeded rice is not specified in different locations and the traditional agronomic practices now being used in DSR cultivation that encounters several problems, such as poor germination and uneven crop growth due to improper land levelling, severe weed infestation at early stages due to non-availability of effective herbicides etc. DSR technology requires proper package of practice for realization of good yields.

2.3 Major constraints under DSR

1. Unexpected rain just after sowing can harm the crop establishment
2. It may result in to reduced availability of soil nutrients viz. N, Fe, and Zn especially in Dry-DSR
3. There may be chances of appearance of weedy rice as a new weed in the crop ecosystem
4. It increases the reliance of farmers on chemical weed management
5. It may lead to occurrence of new soil-borne pests, nematodes, and diseases
6. It boosts emissions of nitrous oxide from soil
7. It also leads to more soil C loss due to frequent wetting and drying (Kumar and Ladha, 2011)

2.4 Types of DSR

The term, DSR, has been remaining with a lot of confusion in peoples' mind. Hence there should be a clear understanding about the types of DSR. Depending upon different factors like land preparation, seeding condition, seeding method, oxygen level in the close vicinity of germinating seed, DSR can be categorized as follows:

1. Dry-DSR: Dry rice seeds are drilled or broadcasted on unpuddled soil either after dry tillage or zero tillage or on a raised bed.
2. Wet-DSR: Pre-germinated (sprouted) rice seeds are either broadcasted or sown in lines on wet/puddled soil.
3. Water seeding: Sprouted rice seeds are broadcasted in standing water.

3. Management of crop under DSR

Crop management under DSR consists of all the practices starting from seed to seed i.e. selection of genotype or variety, site selection, sowing time, method, spacing, water, nutrient and weed management, protection of crop and harvesting. In DSR system; selection of site, soil type, land levelling and weed management have the prime importance. Early crop establishment and canopy growth reduces evaporation and weed population. This is achieved by proper proper plant density, good rice varieties and seedling vigour which reduces the one of the major problems in DSR i.e., weed growth.

3.1 Precise land levelling

Proper land leveling is one of the important prerequisites for successful DSR cultivation. The purpose for proper land leveling is to (1) facilitate even growth and crop establishment, (2) allow uniform irrigation and drainage, (3) reduce the amount of irrigation water, (4) improve input use efficiency like nutrient, water and agro-chemicals, (5) increase cultivation area eliminating bunds for unleveled land, and (6) increase the productivity facilitating all the crop growth requirements. Therefore, precision land leveling should be achieved by laser guided land leveler as it's the entry point to success in DSR. This facilitates to place the seed manually or by drum seeder or by seed drill at uniform distance and uniform depth which results into good crop stand.

3.2 Crop establishment

The method of land preparation differs for conservation (reduced or zero-till) and conventional-till system in DSR. However, in both the cases the land must be weed free and properly levelled at the time of sowing to establish a good crop with most effective plant population. The soil ought to be properly pulverized to maintain an appropriate soil-to-seed contact for traditional dry seeding of rice. In sandy or silt loam soil, there may be the requirement of a proper seed bed with reduced or minimum tillage maintaining soil health and decreasing cost of cultivation. In zero-till dry drill seeding, it's critical to first kill all the existing flora (annual and perennial weeds) with a non-selective herbicide like paraquat (0.5 kg ha^{-1}) or glyphosate (1.0 kg ha^{-1}) prior to seeding. Shifting from PTR to DSR, established of a good crop stand is considered to be an important issue that influences the subsequent growth and development, and ultimately final grain yield of the paddy. The seed rate, uniformity and percentage of germination are important determinants for good crop establishment and yield (Farook et al. 2006a, b). Quality seeds are essential for successful crop establishment. Seed priming induces a wide range of biochemical changes in the seed, the products of which persist following desiccation and are available quickly once seeds are re-imbibed. Therefore, priming accelerates the germination and quick emergence of seeds in DSR.

High seed rates can result in large yield losses due to excessive vegetative growth before anthesis followed by a reduced rate of dry matter accumulation after anthesis and lower foliage N concentration at heading. These factors result in higher spikelet sterility and fewer grains per panicle. Moreover, dense plant populations at high seed rates can create favorable conditions for diseases like sheath blight; and insects like brown plant hoppers) and make plants more prone to lodging. A high seed rate also increases establishment costs. For the continental monsoon-type climate of the Indian subcontinent, the main rice-growing season is during the monsoons (wet season). The best time for seeding of DSR crop under rainfed condition is at least 10–12 days before the onset of monsoons. This would facilitate the timely establishment of the rice crop before rains and reduce seedling mortality brought about by submergence, making efficient use of rainwater and timely planting of a succeeding crop after the rice harvest. However, irrigated condition, the crop can be established both as dry-DSR or wet-DSR depending upon the availability of water as well as proven weed management technology. However, care should be taken for proper drainage facilities during early crop establishment. During dry season, the seeding can be done during early January in areas where low temperature (average temperature < 20^0C) is not a problem, either wise seeding may be deferred for sometimes depending on atmospheric temperatures. The normal practice of crop establishment during dry season is wet-DSR but the crop can also be established as dry-DSR with sprouted seeds where atmospheric temperature does not reduce abruptly during early crop establishment.

For maintaining proper crop stand and good growth the seeding should be done at proper spacing as well as at proper depth with accurate number of seed. For this purpose, the seed should be drilled using a multi-crop seeder with precise seed-metering system. Normal fluted roller type seed-cum-fertilizer drills are less appropriate for drill sowing of rice, because in this the seeds fall continuously which does maintain seed rate and plant population with proper spacing. For accurate and precise spacing, inclined-/cupping-/vertical-plate seed-metering systems are required. Another important factor in DSR is seeding depth which affects the crop establishment. More specifically the seeding depth is very important for semi-dwarf varieties of rice than conventional tall varieties as their mesocotyls are shorter in length. So these varieties should not be drilled deeper than 2.5 cm depth in order to increase the crop establishment contributing to better grain yield.

3.3 Seed priming

Seed priming is a preconditioning process for proper and uniform germination. It is a pre-sowing hydration technique in which seed are partially hydrated to begin the germination process but not radicle emergence. The purpose is to start and accelerate the metabolic process necessary for seed germination prior to actual germination of seed. Seed priming techniques, such as hydro-priming (Farooq et al. 2006c); on-farm priming (Harris et al. 2002); osmo-hardening (Farooq et al. 2006a,b); hardening (Farooq et al. 2004); and priming with growth promoters like growth regulators and vitamins have been successfully employed in rice to hasten and synchronise emergence, achieve uniform stands, and improve yield and quality (Farooq et al. 2006a,b). The seed rate under DSR varies with varying soil type and climatic conditions as well type of crop establishment. It has been reported that seed rate of 20 to 25 kg/ha, in general, is optimum, whereas, fine grain and basmati cultivars require much less seed. Higher seed rate for DSR is not recommended as it may cause N-deficiency in soil, reduced tillering, increased the proportion of ineffective tillers, crop lodging and may create congenial environment for attack of brown plant hoppers.

3.4 Choice of variety

Presently, very limited rice varieties are available that are truly bred DSR. One of the major biotic stresses that compromises yield in DSR is weed infestation.

Development of weed competitive varieties is the easiest and economic strategy both for low- and high-input cropping under DSR. It is more desirable to breed weed suppressive varieties than weed tolerant ones to reduce the weed seed deposition in the weed seed bank in soil. Early seedling vigour is another important character which not only desirable for optimum crop establishment but also makes the DSR crop more competitive to weeds. Slower crop growth rate during the reproductive phase is linked with poor spikelet fertility, which is commonly seen in DSR. So the varieties bred for DSR should have enhanced export ability from the vegetative parts to the reproductive parts during the reproductive and ripening phase of the crop. Lodging is often more problem in DSR than PTR, due to high seed rate, surface seeding leading to less anchorage of roots in soil. Therefore, lodging resistance is another desirable character in DSR having traits viz. intermediate plant height, large stem diameter, thick stem walls, and high lignin content. Early heading rice varieties with better drought tolerance are better suited for dry-seeded rice. Increased plant density and avoiding transplanting shock by using DSR resulted in more biomass than in TPR, which confirmed the advantage of DSR under fully irrigated conditions. This proposes that varieties with more panicles have larger sinks (spikelet number per area) contributing to higher grain yields. When shorter-duration rice varieties are used, DSR system has been reported to yield similar or higher than PTR. Shorter duration of the crop also allows integration of more and different crops to enhance intensification/ diversification of the production system

3.5 Water management

Under rainfed cultivation, provision should be made for life saving irrigation particularly during early crop establishment and grain filling stages. There should be proper drainage system so that excess rain water can be drained out easily during high intensity of rain. In irrigated rice, proper land levelling facilitates uniform water application in less time and helps in weed control which increases water availability for the crop indirectly. Since, water is becoming scarce day-by-day and therefore needs to be utilized more judiciously. So the possible solution to manage the field in a better way in order to increase the water use efficiency i.e. production per unit of water. There are few reports evaluating mulching for rice, apart from those from China, where 20–90% input water savings and weed suppression occurred with plastic and straw mulches in combination with DSR compared with continuously flooded PTR (Lin et al. 2003). The best way to irrigate the dry-DSR is using the method of alternate wetting in drying (AWD) to economize in water use. It was reported that 33-35% irrigation water can be saved by giving irrigation on the appearance of hairline cracks in soil under dry-DSR. Provision of micro-irrigation system like sprinkler irrigation can not only increase the yield up to 18% but also save irrigation water up to 35% compared to the conventional flood irrigation system in aerobic rice. 21 to 74% of irrigation water can be saved when dry-DSR is irrigated with sprinkler irrigation system (30-40 mm) whenever soil water potential fell below 60 kPa at 20-cm depth, producing equal or higher grain yield than PTR (Kato et al. 2009). Extensive research is needed to improve water productivity and WUE in DSR systems. In wet-DSR, the soil should be kept saturated during first 7-10 days to facilitate root and seedling establishment and afterwards a water level at 2-3 cm should be maintained for the next 3 weeks to suppress the newly emerged weeds.

3.6 Weed management

Weeds compete with the crop from the beginning as both and weeds germinate and grow simultaneously in DSR. Having more competitive ability, the weeds grow faster than crop and compete for different growth resources like nutrient, water, light and space which hamper the desirable growth of rice ultimately compromising the rain yield. In this context, tillage may reduce weed infestation up to certain extent by burial of the weed seeds those are present on the surface of the soil, but simultaneously it may allow the weed seeds already buried deep inside the soil to come to the surface and germinate. An integrated approach consisting of preventive methods, cultural practices, stale seed bed technique, agronomic management, selection of weed competitive cultivars and chemical methods is the only feasible and sustainable solution to overcome the weed problem in DSR. In this way the precision agronomy will equip the crop with more weed competitiveness maximizing the productivity. There is a need to develop herbicide resistant rice varieties to facilitate intense rice cultivation under DSR. Some of the best weed control options are given below for DSR (Saha et al. 2018).

3.6.1 Dry-DSR

I. Agronomic management practices

- Plough the field by rotavator or cultivator to get a fine tilth and remove the weeds and crop stubbles before proper levelling for uniform germination and crop stand.
- In heavily weed infested areas, adoption of stale seed bed technique should be a good option. Allowing weed seeds to emerge and then kill either by shallow tillage or by spraying non-selective herbicides like glyphosate, paraquat etc. at least 10 days before sowing is followed under this technique.
- Sowing by seed drill at 15-20 cm apart rows with a relatively moderate seed rate of 35-40 kg ha^{-1} to ensure better crop stand and canopy coverage. In case of mechanical weed control by motorized weeder, sowing should be done at 25 cm apart rows.
- Basal N application should be avoided under DSR as it stimulates weed growth. Apply the recommended nitrogen fertilizer in 3-4 equal splits depending upon the duration of rice varieties, starting from 15-20 days after emergence (DAE) i.e., after initial weed control measures, and rest at 15-20 days interval.

II. Recommended direct control measures

- Spraying early post-emergence herbicide, bispyribac-sodium (25-30 g ha^{-1}) at 10-12 days after emergence (DAE) i.e., at 2-3 leaf stage of weeds to suppress early emergent grasses and sedges.

- Sometimes, efficacy of herbicides is reduced either due to continuous rain or long dry spell prevails following their application or in highly infested fields. Under such situations, sequential application of herbicides is found more effective viz., spray fenoxaprop-p-ethyl (60 g ha^{-1}) against subsequent flashes of grasses and ethoxysulfuron (15 g ha^{-1}) against new flashes of sedges and broad-leaved weeds at 25-30 DAE in sequence with bispyribac-sodium.

- In shallow lowlands or irrigated areas, tank-mix application of fenoxaprop-p-ethyl + ethoxysulfuron (50+15 g ha^{-1}) at 15-18 DAE (2-4 leaf stage of weeds) is found effective against mixed population of grasses, sedges and broadleaved weeds.

- Integration of chemical weed control by spraying bispyribac-sodium at early stage followed by mechanical weed control by operating power weeder at 30-35 DAE is found very effective in shallow lowlands/irrigated areas. Under this management option, crop should be established at 25 cm apart rows. The mechanical weeder also increases soil aeration and consequently tiller production.

- Based on our recent studies, pre-mix application of florpyrauxifen-benzyl + cyhalofop-butyl (25+125 g/ha) and pre-mix application of triafamone + ethoxysulfuron (45+22.5 g/ha) followed by one light manual weeding at 40 DAE results effective control of broad-spectrum of weeds in heavily infested areas.

3.6.2 Wet-DSR

I. Agronomic management practices

- Dry tillage one month before final land preparation for removal of perennial weeds followed by puddling twice at 7-10 days interval and proper land levelling to ensure uniform crop stand.

- Keep 3-5 cm standing water in the field between two puddling helps in easy decomposition of weeds and crop stubbles.

- Sowing by drum seeder at 20 x 15 cm spacing (15 x15 cm during dry season) on moist saturated soil with 30 kg seeds ha^{-1} to ensure better crop stand and canopy coverage. In case of mechanical weed control by motorized weeder, row spacing should be adjusted to 25 cm.

- Keep the field under saturated moist condition for initial 7-10 days of sowing (DAS) to facilitate better root and seedling establishment and then keep a thin film of water (1-2 cm depending upon the seedling length) up to 21 DAS.

- Apply the recommended dose of 'N' in 3-4 equal split at 15-20 days interval escaping the basal dose as it encourages early weed competition.

II. Recommended direct control measures

- Spray bispyribac-sodium (25-30 g ha^{-1}) at 12-15 days after sowing (DAS) i.e., at 2-3 leaf stage of weeds to suppress early emergent grasses and sedges.

- Sequential application of bispyribac-sodium (30 g ha^{-1}) at 10-12 DAS followed by ethoxysulfuron (15 g ha^{-1}) at 25-30 DAS shows effective control of weeds in areas where subsequent flashes of weeds particularly sedges and broadleaved weeds appear under controlled water condition
- Spraying of herbicide mixtures viz., fenoxaprop-p-ethyl + ethoxysulfuron (50+15 g ha^{-1}), penoxulam + cyhalofop-butyl (25+100 g ha^{-1}), florpyrauxifen-benzyl + cyhalofop-butyl (25+125 g/ha) and triafamone + ethoxysulfuraon (45+22.5 g/ha) spray at 15-18 DAS are showed broad spectrum of weed control in fields with mixed population of weeds
- Spraying bispyribac-sodium at 10-12 DAS followed by mechanical weed control by operating power weeder at 30-35 DAS is an alternative option for effective control of weeds under W-DSR. Under this management option, crop should be established at 25 cm apart rows.

The selection of herbicide/herbicide mixture and its correct time of application with proper application rate is one of the most important criteria for effective weed control in rice field. Some important herbicides and ready mix/ or tank mix combinations of herbicides are listed below in Table 1 with details protocol.

Table 1. Recommended herbicides for weed control in DSR (Source: Saha et al. 2018)

Sl. No.	Name	Target weeds	Time of Application	Dose (g a.i. ha^{-1})
A. Dry-DSR Grasses and sedges are prevalent at early stages. Sometimes, due to relatively aerobic soil conditions, several flashes of weeds generally appear during critical period of crop weed competition.				
1.	Bispyribac-Sodium	Early emergent grasses and sedges	10-12 days after emergence (DAE) / OR at 2-3 leaf stage of weeds	25-30
2.	Fenoxaprop-p-ethyl	Late emergent grasses	25 DAE / OR at 3-5 leaf stage of weeds	60
3.	Ethoxysulfuron	Sedges and broadleaved weeds	15 DAE / OR at 2-4 leaf stage of weeds	20
4.	Fenoxaprop-p-ethyl + Ethoxysulfuron (Tank-mix)	Mixed weed population	15-18 DAE / OR 3-4 leaf stage of weeds	50+15

5.	Florpyrauxifen-benzyl + Cyhalofop-butyl	Mixed weed population	15-18 DAE / OR 3-4 leaf stage of weeds	25+125
B. Wet-DSR Grasses and sedges are prevalent at early stage and mixed weed population appears at late vegetative stage however their dominance depends on water level in rice fields				
1.	Bispyribac-Sodium	Early emergent grassy weeds and few sedges	10 DAS / OR at 2-3 leaf stage of weeds	25-30
2.	Ethoxysulfuron	Late emergent sedges and broadleaved weeds	18-22 DAS / OR at 2-4 leaf stage of weeds	15-20
3.	Fenoxaprop-p-ethyl + ethoxysulfuron (Tank-mix)	Mixed population of weeds	15-18 DAS / OR at 3-4 leaf stage of weeds	50+15
4.	Penoxulam + Cyhalofop-butyl (Pre-mix)	Mixed population of weeds	15-18 DAS / OR at 3-4 leaf stage of weeds	25+100
5.	Florpyrauxifen-benzyl + Cyhalofop-butyl	Mixed population of weeds	15-18 DAS / OR at 3-4 leaf stage of weeds	25+125
6.	Trifamone + Ethoxysulfuraon (Pre-mix)	Mixed population of weeds	15-18 DAS / OR at 3-4 leaf stage of weeds	45+22.5
7.	Bensulfuron-methyl + Pretilachlor (Pre-mix)	Mixed population of weeds	5-7 DAS	60+600

3.7 Nutrient management

Due to alternate wetting/drying cycle more aerobic condition persists in dry-DSR, which reduces the availability of several nutrients including N, Zn and Fe. This condition also suits to increase the nitrification/denitrification, volatilization, and leaching losses of N more in dry-DSR than in wet-DSR and PTR. Deep placement of fertilizer and use of controlled-release fertilizer are proved to perform well under rainfed conditions. Moreover, balanced fertilizer application is one of the important components of integrated weed management in DSR as it affects the weed population and hence rice-weed competition (Camara et al. 2003). With respect to physical and chemical properties, rice soil differs greatly from DSR to PTR. N efficiency can be increased by adopting N efficient varieties, improvement of timing and application methods and better incorporation of N fertiliser without standing water (Ali et al. 2007). Split application of N was reported to increase N fertilizer use efficiency, reduce denitrification losses, match the crop demand and N uptake subsequently increasing the grain and straw yield and harvest index (Bufogle et al. 1997).

Split application of K i.e. 75% as basal and the rest 25% at the time of final top dressing of N, has also been recommended for DSR in medium textured soil. Micro-nutrients like Zn and Fe are more commonly deficient in aerobic or non-flooded soil than flooded one. So in dry-DSR system, micronutrient fertilization is important. Zn deficiency can be corrected by basal application of 25 kg ha^{-1} $ZnSO_4$. Basal application of Zn is better than foliar application; however, if basal application of Zn is missed, then it can be top dressed up to 45 days. For correction of Fe deficiency, foliar application of fertilizer is better than soil application. A total of 9 kg Fe ha^{-1} in three splits (40, 60, and 75 DAE) as foliar application (3% of $FeSO_4$ $7H_2O$ solution) has been found to be effective.

3.8 Protection from pests and diseases

Rice is susceptible various diseases, among which blast is the most devastating one that mostly occurs and becomes severe in water limiting conditions i.e. under aerobic and DSR cultures (Bonman and Leung, 2004). Countries like Brazil is giving emphasis on the breeding programme focusing on blast resistance trait (Breseghelo et al. 2006). The shift from PTR to DSR culture has favoured neck blast spread in rice. It has been reported that the level of water supply affects several process viz. spore liberation, germination and infection in rice blast epidemics (Kim, 1987). Therefore, water management directly affects the microclimate in rice ecology, which indirectly affects the life cycle of the pathogens spreading the disease and the physiology of the crop inducing the host susceptibility (Sah and Bonman, 2008). Poor water management develops moist or dry soil condition in DSR that is different in PTR system which is flooded and wet. This increases the host susceptibility for blast development. Higher frequency of other diseases like ragged stunt virus, yellow orange leaf virus, sheath blight, brown spot and dirty panicle are observed in DSR compared to PTR whereas sometimes other arthropod insect attack is found less in DSR (Pongprasert, 1995; Savary et al. 2005). Incidence of soil borne pathogenic fungus *Gaeumannomyces graminis* var. Graminis and root-knot nematode are seen in rice when shifting from PTR to DSR system (Prot et al. 1994).

4. Conclusion and future outlook

Some researchers believe that DSR could not be popularised over the years because of extensive weed problem associated with it (Johnson and Mortimer, 2005). Many researchers reported that manipulation of crop fertilization is a hopeful agronomic practice in reducing weed interference in crops (Cathcart et al. 2004). Along with this, deficiency of micronutrient viz. Zn and Fe, because of imbalanced N fertilization and high infiltration rates in DSR is also a major concern. Farmers are interested to adopt DSR only due to shortage of water and labour and soil degradation under intensive PTR. Despite several challenges confronting DSR, many opportunities exist.

It is realized that (1) optimal plant architecture, and (2) rapid emergence and subsequent good establishment during the early stage of rice growth in DSR would play an important role in success of DSR. These two factors are the important development which has led to development of different improved management practices in DSR viz. land levelling, seeding with proper depth, density and distance, stand establishment, proper fertilization, water and weed management that can ensure higher productivity. Alike agronomic management, breeding of DSR specific varieties with appropriate traits is also the need of the time to achieve maximum potential under DSR. A lot of efforts has been given by many researchers to develop improved management practices under DSR, however more research is required especially in weed management aspects under DSR addressing the key issues like weed flora shift, emerging weedy rice problem, unavailability of new molecules of herbicides as well as tank/ready mix herbicide mixtures to control population dynamics of broad spectrum weed flora examining their vulnerability and controllability with environmental impact which will minimize/ avoid/ delay the development of herbicide resistance in weed population. These problems need to be addressed by scientists and extension personnel for development and wide adoption of a successful DSR system.

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Chapter 08

Crop diversification and efficient water management for making rice based production system climate resilient

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Abstract

Crop diversification is a an agronomic management by inclusion of rice-based cropping systems (RBCS) mainly with pulses/legumes and oilseeds in rice fallows. This practice not only ensures system productivity and economic stability to farmers but also showed its beneficial role in changing climate scenario. Moreover, climate-smart agriculture (CSA) suitably provides more options of crop diversification with other crops like maize, groundnut etc. has been evolved as resource conserving technologies, especially in eastern India. However, success of RBCS depends on agro-climatic situations, and relies on secured irrigation and performs better in well-resourced situations. Here in this chapter, different management options under RCBS, its advantage and suitability for CSA has been discussed along with efficient water management practices.

Keywords: Climate resilience, cropping system, crop diversification, water conservation, climate change adpatation

1. Introduction

Rice is staple food grain crop in India and an important food crop for approximately 70% of the world's population. It is cultivated in around 100 countries in the world covering 163 million ha with a production of 740.9 million tons which is slightly lower than the global requirement of 765 million tons by 2025 (Sravan et al. 2018). The development of high yielding, short-duration and thermal insensitive rice varieties has paved the way for multiple cropping systems in the country involving a wide range of crops. Horizontal expansion of rice-based cropping systems (RBCS) is possible by crop diversification with the inclusion of pulses/legumes and oilseeds in rice fallows. Intensive cultivation in RBCS has heavily dependant on irrigation to produce more under well resourced and a predictable situations. This is possible due to multiple cropping systems either through double cropping or triple cropping. However, rice production is facing the problems of water scarcity and weather abnormalities like drought, flood, cyclones, etc. However, the system has been highly fragile due to its high dependency on energy, technologies, and infrastructures and is highly exposed to production cycle disruption. In addition, the changing climate and its consequences are aggravating the situation of degradation and non availablity of natural resources, *viz.* soil, water, air, etc. As rice fields are flooded while irrigating, it leads to anaerobic soil conditions conducive for of methane (CH_4) Production. The contribution of CH_4 emission from rice fields (around 36 Tg year^{-1}) is approximately 18% to the total anthropogenic CH_4 emission to the atmosphere (Tivet and Boulakia, 2017). Thus the RBCS is facing the dual challenge of meeting food demands of growing population while addressing the issues such as climate change, water scarcity and soil degradation through sustainable agricultural intensification.

Climate-smart agriculture (CSA) involving resource conserving technologies are evolving as a efficient and sustainable alternative to conventional practices in south Asian countries yield stability (Jat et al. 2021). Transfering the climate-smart rice based production technlologies farmers field demands for good availability of irrigation water at right time and the drainage system to remove any excess water. Designing rice-based cropping systems capable to fitting to the irrigation and drainage capacities of individual farm of hydraulic unit level can improve the land productivity and profitability. The next alternative is to go for crop diversification. This can be done by the inclusion of such crops in the cropping system after rice like maize, wheat, green gram, black gram, chickpea, lentil, Lathyrus, linseed, potato, boro rice, groundnut, pigeon pea, etc based on the suitability to the rainfall pattern of the area as well as to the available crop duration and irrigation facilities.

2. Rice-based cropping systems

Rice-based cropping system is the backbone of agriculture production in the country. It is important in maintaining the food security of the country and at the same time maintaining the livelihood security of small and marginal farmers. Rice is grown under both irrigated and rainfed conditions. Earlier the rice varieties/cultivars were tall, long duration, low-yielding with low response to applied inputs and lower harvest index. Improvement in varietal characterstics i.e. short duration, dwarfing, photo-insensitive, and input responsiveness and high yielding has encouraged multiple cropping involving a wide range of crops. Arrangement of crops in RBCS is mainly dependent on agro-climatic conditions of the region.

A large number of cropping systems are in practice in different parts of the country that includes cereals, cereals, pulses, oilseeds, vegetables and fibre crops as the second crop in the system depending upon the land situation. Rice – rice rice system is the dominant cropping system in the eastern and south India while rice – wheat in the north and western India. So far, researchers have been focusing on management of individual crops disregarding the fact that each cropping system needs a differential management to make the system productive and climate resilient. Different types of RBCS practiced in the country have been presented below.

2.1 Mixed varietal rice cropping

In this system, seeds of rice varieties having different maturity duration are used to mixed in a definite ratio (1:1) and sown in field which yields more under adverse conditions. This system is a common practice in West Bengal to avoid total crop loss at the times of flood.. Similarly, in Tamil Nadu and Kerala, a mixture of autumn and winter varieties in 3:1 ratio is frequently in practiced. However, under favourable conditions, it hinders in performing common agricultural operations like harvesting and fertilization.

2.2 Intercropping of rice with other crops

In the upland or hillly conditions rice is also intercropped with blackgram, greengram, sesame, maize, finger millet or other minor millets. This is a is a commonly practiced in north and north-eastern part of the country following a rice and intercrop ratio of 3-4:1.

2.3 Relay/paira/utera cropping

Relay or pyra cropping is a common practice in rice fallows of easter India to address the moisture stress in dry season. The seeds of short duration pulses like lentil, black gram, bengal gram, pea, lathyrus, berseem, linseed etc. is broadcasted in maturing rice crop. Relay cropping saves time, reduces tillage cost and uses residual soooil fertility.

3. Advantages of cultivating rice in a multiple cropping

Diversification of rice –rice system to rice – pulses /oilseeds brings in many advantages to the system. It helps in the improvement of soil health, reduction of d the water demand, and enhancing water productivity (Arora et al. 2020). In Punjab, when rice was replaced with soybean under rice – wheat cropping system, under a raised bed system, it improved soil fertility and saved water. Thus, the inclusion of legumes in the cropping system could improved the nitrogen economy leading to cropping systems' sustainability and reduction in cost of cultivation (Arora et al. 2020). Similarly, the substitution of rice with less water demanding crops viz. cotton, maize, pearl millet, or legumes in the wet season, substantially reduced the water requirement and helps in allocating water to the dry crops during the monsoon season leading to higher water productivity in northwest India. (Arora et al. 2020). The maize crop being a cereal with high production potential can be the most viable alternative to puddled transplanted rice as it needs only one-fourth of water required by rice to produce one killogram of grain, records higher water productivity (> 8 – 22 times) (Gathala et al. 2013) and better soil health (Jat et al. 2012) in terms of enhanced total microbial and enzymatic activities in soil, such as phosphatase, invertase, β-glucosidase, and urease (Wei et al. 2015) compared to rice.

4. Diversification of cropping system in changing climate

The climate resilience of the rice based cropping systems can be improved through crop diversification either in space (replacing one crop with another) or in time (modifying the crop in rotation or cropping system). Diversifying the rice based system to non rice based system can address the issue of water stress. For example, the rice-wheat system in north Indian states or rice – rice system in eastern or south Indian states are water resource-intensive system and more vulnerable to global warming as demand for irrigation water increases with temperature. Adoption of less water-intensive cropping systems (e.g. maize–wheat system) or rice – pulses/ oilseeds can enhance the production and profitability by mitigating the moisture stress arise due to climate change. (Pimentel et al. 1997; Akanda 2011). Farmers in India use leguminous crops, mostly red gram, green gram, and groundnut in dry season to supplement nitrogen to the soil which is normally lost due to soil erosion or flooding during wet season. Thus, small and marginal farmers can better cope up with climate change through diversification of the existing rice based cropping systems with less resource or input requiring cropping systems.

4.1 Managing cropping systems for climate change adaptation

Crop management plays a major role in the climate change adaptation and mitigation. Moisture stress is a common phenomenon of climate change. Adaptation of drought/temperature tolerant varieties, water saving rice cultivation methods (SRI, aerobic, direct seeding), community nurseries, changing the planting dates, mechanization, location specific mixed or intercropping systems with high but stable yields can reduce the negative impacts of climate change. Temperature rise becoz of climate change affects the water requirement and evapotranspiration from crop fields leading to higher heat stress. Under such conditions millets can be a better option for integration in the rice based cropping system. The introduction of short duration and improved varieties of pigeon pea, soybean, wheat, and sorghum can enhance the yield level by 75%, 15%, 27%, and 91%, respectively (Sonune and Mane, 2018).

Like moisture stress, a large proportion of rice growing areas in India also suffers from water stagnation and submergence due to flooding in wet season. Almost 80% of the rice-growing areas in Eastern India are rain-fed and thus suffer either from flood or drought. In wet season, the varietal diversification can help to address the changing situation as crop diversification in lowland rice areas is limited. In eastern India, rice is being cultivated during the rainy season (June–September) and land normally remains fallow after the rice harvest in the post-rainy season (November–May) particularly in upland and medium lands due to non-availability of of sufficient rainfall or irrigation facilities. However, in lowland areas, sufficient residual soil moistures are available in rice fallows to raise a less water requiring second crops in the region (Lal et al. 2017). Flood-tolerant rice variety i.e. Swarna sub-1 can help in adapting to these excess water stresses (Reyes, 2009) and drought-tolerant rice varieties such as Sahbhagidhan, DRR 44, and Sushk Samrat can help farmers in eastern India to cope up with moisture stress. Additional approximately 1 t/ ha yield can be achieved with these varieties over the irrigated varieties under adverse conditions. Effect of drought and flood is equally severe also in other dry crops in the RBCS. For example, drought is responsible for 15–20% yield loss in maize in south Asian countries. Some of the drought-tolerant maize varieties from CIMMYT even yields 1 - 2 t/ha more under drought conditions (Zaidi et al. 2004). Heat tolerant wheat varieties like DBW 16, Raj 3765, Lok 1 and GW 322 also report yield advantages.. Maize varieties like HQPM-1 and HHM-1 are tolerant to both cold and frost, while HM-1 is tolerant to frost only. Chickpea varieties like JG 11, that are tolerant to heat can be promoted in rainfed areas of eastern India.

Besides, introduction of new crops, change in planting time can produce stable yields under changing climate.. more than 4% yield advantage has been reported by shifting the planting date of wheat and transplanting date of rice by 15 days earlier than the usual date (Jalota et al. 2013). However, delaying the sowing dates in soybean helps in reducing the the yield lossin India. In drought-prone areas of India, diversification of rice to sorghum and following staggered planting can spread risk (Satapathy et al. 2011).Therefore, adopting the optimal management practices can be the best way of addressing the negative impacts of climate change.

5. Water Management in rice for developing system climate resiliency

Water scarcity is a reality now. The causes for water scarcity are diverse and location-specific, but include decreasing water resources, decreasing water quality, malfunctioning of irrigation systems, and increased competition from urban and industrial users. Optimal irrigation of the rice based cropping systems is not possible due to this water scarcity.

Cultivated rice (*Oryza sativa*) is an annual grass which likes water but not an aquatic plant. However, water management in conventional lowland rice is normally refer to continuous flooding from crop establishment to harvesting. Rice is extremely sensitive to water shortage. Most rice varieties develop symptoms of water stress when the soil water content drops below saturation. Sound water management practices are needed to use water wisely and maximize rice yield. Irrigation is the single most important strategies to contain the negative effects of climate change on cropping systems. Scientifically managing water in a rice field not only saves water but also improves the productivity of rice. Further efficient utilization of the saved water in other dry crops enhances the system productivity.

A suite of options are available to help farmers cope with different degrees and forms of water scarcity. During crop growth, techniques such as direct seeding, saturated soil culture, alternate wetting and drying, raised beds, mulching, and aerobic rice can use the available water efficiently. A number of water-saving technologies have already been developed for irrigated paddy/lowland rice production which have been presented below.

i) **Saturated soil culture (SSC)**: In SSC the soil is kept as close to saturation as possible withot much seepage and percolation losses. A shallow irrigation is given to obtain about one centimeter of ponded water depth a day or so after the disappearance of ponded water. It saves about 5 to 50% water depending on soil type and groundwater table depth with about of 5-10% yield loss. Raised beds is an effective way to keep the soil around saturation. The rice plants are grown on beds and the water in the furrows is kept close to the surface of the beds.

ii) **Alternate wetting and drying (AWD)**: In AWD irrigation rice crop is flooded after passage of certain number of days after the disappearance of ponded water. AWD is also called 'intermittent irrigation' or 'controlled irrigation'. The irrigation interval in AWD varies from one day to more than 10 days. The depth of the water table is monitored on the field using a simple perforated 'field water tube'. After an irrigation, the water depth in the tube gradually decrease with time. The crop is again irrigated after the water level reaches 15 cm below the surface of the soil to bring back the water level to 5 cm above the soil surface. However, during flowering, from 1 week before to one week after the peak a constant water level of 5 cm above soil surface is maintained.. The threshold of 15 cm is called 'Safe AWD' as this does not cause any yield decline. The roots of the rice plants used to take up sufficient water from the saturated soil and the perched water in the root zone. However the safe AWD limit may vary with soil type. In Safe AWD, water savings upto 15% withot any yield penalty.

iii) **Mulching**: Various methods of mulching have been tried in non-flooded rice systems, and have been shown to reduce evaporation as well as percolation losses while maintaining high yields. However, the left-over plastic after harvest may cause environmental degradation if not properly taken care of.

iv) **Raised bed system**: In the system of raised beds, rice is grown on beds that are separated by furrows through which the irrigation water is coursed. In general, furrow irrigation is more water efficient than flash-flooding, and furrow irrigation should hold promise for aerobic rice. Though dimensions may vary, beds are usually around 35 cm wide, separated by furrows that are 30 cm wide and 25 cm deep. Rice can be transplanted or direct seeded on the beds. So far, the raised bed system has mostly been tested with existing lowland rice varieties, and yield gains may be expected when suitable aerobic varieties are developed /used. However, raised beds for rice are still in the experimental phase and a number of problems still need to be overcome, such as risk of iron deficiency, weed infestation, accurate sowing depth, and nematodes.

v) **Direct seeding (Dry/wet)**: If plot-to-plot irrigation is practiced and no opportunities exist to construct field channels to irrigate seed beds, direct wet seeding may be an option to reduce water use in the land preparation period in large-scale irrigation systems. Dry seeding can also increase the effective use of rainfall through early crop establishment and hence reduce irrigation needs. However, when seed beds can be separately irrigated from main fields, a transplanted system will require less water than direct seeded rice since the total duration of the crop in the main field is shorter. Farmers can reduce water use by shifting from puddled to non-puddled land preparation in a direct dry-seeded system. Dry seeding with subsequent flooding is only possible in heavy (clayey) soils with low permeability and poor internal drainage that do not require prolonged puddling to create an impermeable layer.

vi) **Aerobic Rice**: Aerobic rice is a direct seeded rice production system in which especially developed "aerobic rice" varieties are grown in well-drained, non-puddled, and non-saturated soils. Aerobic varieties are intermediary to high yielding lowland rice and upland rice. Aerobic rice saves 30-50% compared toflooded lowland rice. Aerobic rice is suitable for uplands with sufficient rainfall to keep the soil water content close to field capacity or fields on undulating, rainfed lowlands or water limited irrigated lowlands. The usual establishment method is dry direct seeding. Aerobic rice can be cultivated following onservation agriculture practices such as mulching and minimum tillage. It can be irrigated using sprinklers, drip irrigation, furrow irrigation, or flas flooding method. Unlike flooded rice, crop is irrigated to just bring the soil water content in the root zone up to field capacity. Standard nutrient management practices are followed. However, chemical and mechanical weed management can be easily practiced in aerobic rice. It can be cultivated with other dry crops in rotation.

6. Conclusion

Rice-based cropping systems are more vulnerable to climate change as the system requires a large amount of water. However, the issue can be solved partially through diversification of the existing rice based production system to low water requiring cropping systems. Further, changing the water management practices of individual crops and rice in particular following system approach and adoption of water saving or efficient rice production systems can mitigate the cause of climate change. Thus, better agronomy of crops (efficient irrigation in particular) is the best way of addressing climate change in rice-based cropping system.

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Chapter 09

Conservation Agriculture and Resources Conservation Technologies for Climate Resilient Rice Production Systems: Special Reference to Eastern India

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Abstract

Achieving the food and nutritional security will remain focal point in many developing countries. According to World Bank report (2020) nearly 690 million people or 8.9 percent of the global population are hungry i.e nearly 60 million people added in the 5 five year). Moreover, we need to produce about 70 per cent more food by 2050 to feed an estimated growing population of ~ 9.8 billion people. Food production system is often dictated by extremes of weather and vulnerability to climate change. In fact, climate changes pose negative impacts due to increasing temperatures, weather variability, shifting agro-ecosystem boundaries, invasive crops and pests, and more frequent extreme weather events. On farms, climate change is adversely impacting/reducing crop yields, the nutritional quality of major cereals, and reducing the livestock productivity. Therefore, substantial investments are essential for adaptation to maintain current yields and also sustain food production. Thus, there is an urgent need for climate resilient agriculture (CRA) in this region. The CRA does not allow any adverse effect of climate change on ecology of soil and environment as well as agricultural productivity. The CRA also strengthens food and nutritional security and also delivers environmental benefits. In this chapter, we discussed about various aspects of climate resilient agriculture techniques and sustainable soil management practices for higher crop production and sustainability.

Keywords: Climate resilient agriculture, climate change, sustainable soil management, site-specific nutrient management, soil health

1. Introduction

Rice is the important staple food for nearly half of the world, and it is grown for 6000 years in different parts of Asia. In India, rice crop plays an important role in diet, economy and culture. India ranks first in area and production of rice in world (Pathak et al. 2018). The states including Punjab, West Bengal, Andhra Pradesh, Uttar Pradesh, Chattisgarh, Odisha and Bihar etc. are the leading rice producing states in India. It was estimated that global rice production needs to be enhanced from current rice production of 493 Mt to 550 Mt in 2030 (IRRI 2016) to meet the demand. However, present rice production system faces multiple challenges and problems such as land degradation, climate change, weather extremes, attack of pest and diseases etc.

Eastern India is the major rice growing region of the country which includes Assam, Bihar, Jharkhand, West Bengal, Chhattisgarh, Jharkhand, Odisha, and Eastern Uttar Pradesh. The region is one of the unique biomes and serves as a food basket of India next to Punjab. The region has a total population of 405.94 million (m), contributes about 34% of India's population. The population density of eastern states is 1.62-fold higher than the national average (Bhatt et al. 2011). In eastern states, population density is highest in West Bengal (1029 person/sq km) and lowest (189 person/sq km) in Chhattisgarh. The livelihood of most of the population is at the stake as 116 million people are still below poverty line (BPL) in this region (Provisional Census, 2011; Statistical Abstract India, 2007 and Agricultural Statistics at a Glance, 2010).

Out of total geographical area of eastern India 71.84 million hectare (m ha), about 31.1 m ha (43.3%) is the net sown area. This region has the cropping intensity of 150% as against the national average of 139% (National Wetland Atlas, 2011). Among the different soil types occurring in the region, the alluvial soils are the dominant soil type (covering 40.5% area of the region), followed by yellow and red soils (25.5%), red-sandy soils (13.6%), red loamy soils (8.7%), *tarai* soils (6.1%), lateritic soils (5%), and grey and brown soils (0.70%). Out of these, about 7.5 m ha area under acidic soils, 3.18 m ha under saline and sodic soils (Sharma and Chaudhari, 2012). A total of 4.05 m ha area is under wetland in eastern region. West Bengal has the highest area (1.1 m ha) under wetlands, followed by Assam (0.752 m ha) and lowest wetland area is in Jharkhand (National Wetland Atlas, 2011).

Though the eastern region receives high to very high rainfall, however, there is a need to increase the water productivity. The average water productivity for the region varies in the range of 0.21 (Odisha) to 0.61 kg m^{-3} (Eastern UP), which is relatively low as compared to Punjab (1.01 kg m^3). Therefore, efforts are required to increase water productivity through increasing the yield as well as efficient utilization of water resources through its multiple uses, farming system mode of food production and by adopting the concept of *'more crop per drop of water'*.

1.2 Farming activities in Eastern region

This region experiences wide usage in fertilizer consumption. Data indicated that the highest consumption of NPK in Bihar (258 kg/ha), followed by West Bengal (174.5 kg/ha) (FAI, 2020-21). However, the rest of the states, fertilizer consumption ranged from 114 to 135 kg/ha with an average of 158.4 kg/ha as against the national average of 161 kg/ha (FAI, 2020-21). Thus, there is an urgent need to adopt the practices of integrated and balanced nutrient management to increase the agricultural production besides maintaining the soil health.

The average food grain productivity during *Kharif* in this region is almost at par with the national average, but the food grain productivity during *Rabi* is lagging than the national average (20.5% less). Among different states, West Bengal has the highest food grain productivity in *Kharif* (wet season) as well as *Rabi (dry season)*, whereas Chhattisgarh has the lowest productivity, during both *Kharif* and *Rabi* seasons.

1.3 Need for Climate resilient of Agriculture

According to World Bank report (2020) around 690 million people (8.9% of the global population) are hungry, which is increased by around 60 million in the last 5 years. The food security challenge would be more severe, as we will need to produce about 70% more food by 2050 to feed around 9.8 billion people (Stewart and Robert, 2012). This situation is further intensified with the increasing vulnerability of agriculture to climate change. The negative impacts of climate change are experienced in the form of increasing temperatures, weather variability, shifting of agro-ecosystem, invasive crops and pests, and more frequent extreme weather events (McCarthy et al., 2011). At farm level, climate change adversely impacting crop yields, the nutritional quality of major cereals, and reducing the livestock productivity. Therefore, considerable investments are required for adaptation to maintain current yields and also sustain food production. Thus, there is an urgent need for climate resilient agriculture (CRA) in this region.

1.4 Climate Smart Agriculture Vs. Climate Resilient Agriculture

Climate-smart agriculture (CSA) is an "integrated approach to manage landscapes-cropland, livestock, forests and fisheries"-that addresses the dual challenges, i.e., food security and accelerating climate change. The CSA aims to simultaneously addresses multiple benefits outcomes namely, enhanced productivity; improved resilience; food, nutritional and livelihood security; and reduced GHGs emissions.

The CSA does not allow any adverse effect of climate change on ecology of soil and environment as well as productivity of agricultural crops, but climate resilient agriculture (CRA) is an inbuilt mechanism of the system that recognizes the threats that needs attention. Climate smart means anything which is planned effectively in advance to encounter vagaries of climate change so that its effect may be minimized. This may involve avoiding stress or tolerating stress with any set of procedures. However, climate resilient is something which can tolerate the stress arising out of a set of conditions.

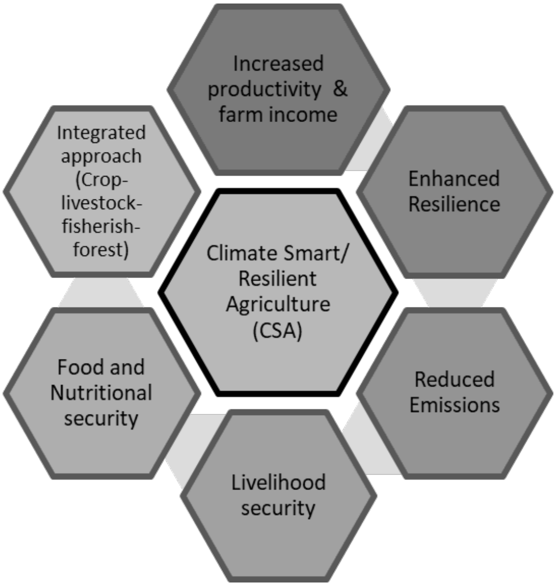

Figure 1. Approaches of climate resilient agriculture

2. Major soil related constraints in eastern India

This region experiences many soil related constraints some of them are i) low productive acid, saline and sodic soils, ii) fine textured soils having prolonged submergence, iii) high accumulation of *kankars* of Ca, Fe and Mn in the solum of paddy profile and other water submerged areas, iv) hard pan of calcic and gypsic layer in the subsurface layer, v) deficiency of N followed by P in calcareous soils, vi) high water table and waterlogging, vii) Soil erosion, viii) low water holding capacity, and x) soil contamination (arsenic, iron- manganese toxic Soils)

2.1 Strategies for natural resource management in Eastern India

Soil organic carbon enhancement improve soil fertility status, increases soil-water holding capacity, soil aggregate stability, cation exchange capacity (CEC) and nutrient-mineralization. The nitrogen-fixation of soil significantly affected by soil temperature and moisture regimes, nutrients status and microbial activities. The extent of N-fixation influences the nitrogenous fertilizer use and their use efficiencies. Management practices such as conservation/optimum tillage, fertilization (INM), crop rotation, water management, liming and crop cover that can significantly affect the productivity of the soil. Adoption of low-input farming as well as site specific fertilization where soil nutrient status is low and fertilizer use has been least helping in improving crop yield and soil health. Cultivation of higher nutrient efficient crops and cropping systems would be an important component of the adaptation under climate change scenario. In addition, cultivation of short duration and drought tolerant rice varieties such as Vandana, Tulsi, Rajshree and Rajendra Mahsuri, Rajendra Sweta and Swarna in flood-prone areas of Bihar/eastern region must be adopted by the farmers. Other practices such as zinc sulphate application in the rice crop in zinc deficient areas, adoption of bio drainage in waterlogged areas, providing irrigation at critical stages of crop growth are proved beneficial in the region.

2.2 Soils of eastern region and their management

The problematic soils recognized in the region are: (a) Acid soils, (b) Salt affected soils, (c) Calcareous soils, (d) Tal land soils, (e) Diara land soils, (f) Chaur land soils, (g) Waterlogged soils, (h) High bulk density layer soils, and (i) Eroded soils

2.2.1 Salt affected soils

Various farm management practices recommended for reclaiming sodic soils are: proper land levelling and bunding; judicious application of gypsum and pyrite; green manuring; optimum application of fertilizers (particularly Zn fertilizers) and manures; integrating fertilizer N with organic sources, viz., pressmud, FYM and water hyacinth increased the yield attributes, grain yield and N use efficiency in rice, and improved the physical and chemical properties of soil (Ref?). Prolonged pre-submerge (i.e., 25-35 days) of rice field has been found effective for amending calcareous sodic soil. The effect of submergence on calcareous soil was found more distinct when FYM was applied to the field. Rice is preferred as potential crop in alkali soils as it can grow under submergence, and it can tolerate fair level of exchangeable sodium percentage (ESP). Similarly, crusting can be reduced using phosphogypsum (to decrease run-off and erosion), mulching, residue management, conservation-tillage, and other techniques which increase soil organic carbon content.

Table 1. Recommended good agronomical management practices for sodic soils

Problem soils/ Strategies	**Possible /Interventions**
Sodic Soils	• Land preparation with 30 cm high bunds to ensure rainwater storage and uniform distribution of irrigation water. • Surface water stagnation for a minimum of 15 to 20 days before transplanting improves rice production. • Planting seedlings of older age (35-40 days) and higher plant population (45-60 hills m^{-2}) give better results. • Green manuring with rice helps to overcome N deficiency problem. • The soils are deficient in organic matter. Therefore, the application of 15-20% more N compared to normal soils is recommended. The soils are generally well supplied with P and K and could be withheld for first three to four years. • Application of Zinc @ 10 - 15 kg $ZnSO_4$/ha to rice has been found very beneficial in these soils.

Flood prone areas *Diara* and *Tal* land cultivation	• Deep ploughing and drainage can improve the soil. • Incorporation of crop residues like rice husk improves the air-water relationships in soil mass and checks the formation of hard clod. • Traditionally monocropped tal lands can be converted into double cropped area provided the irrigation facilities are created. • A short duration crop of rice, maize, vegetables etc., can easily be taken during summer before the occurrence of floods. • Irrigation Management for Cropping system: Presence of an additional crop in inter / sequential cropping may have an important effect on reduction of evapotranspiration. ***Irrigation management for integrated farming systems (IFS):*** Water use efficiency can be increased by increasing the total farm output with the efficient utilization of available water. This is possible if we integrate one of two alternative agricultural allied enterprises other than cropping component depending upon the feasibility of the farmers, marketability for the farm products in the locality. Besides other management practices, effective recycling of organic residues improve soil health and increases water holding capacity, crop yield and water use efficiency.
Conservation soil moisture/ control evaporation	• Evaporation loss of soil moisture: 20 to 30%. • It can be effectively reduced by modifying the albedo of the soil through synthetic and organic mulches. • In vegetable crops, both straw (6-10 t/ha) and polyethylene (25 - 70 µ thickness) mulching conserve moisture. • Presence of residues on the surface reduces water evaporation from soil by 34-50%. • Effect of mulching is seen more in *rabi* crops than *kharif* crops. • Shallow and fibrous rooted crops benefit more than deep rooted crops from mulching.

Application of manures and fertilizers to retain optimum soil-water for the crop	• Addition of phosphorus and nitrogen have an effective role on water use by regulating the physiological efficiency of plant. • Use of manures, gypsum, lime and phosphatic fertilizers to improve soil structure. • 1.0% increase in organic matter content increases the available water by 1.85% (v/v). • Only three tones of humas could be formed from application of 30 tons of FYM as such on spreading on the field. However, 5 tons of humus can be generated by application of the same amount of compost. • 70% of Indian soil contains less than 1.0% organic matter (for optimum fertility status of soil: >5%). • The frequent addition of animal manure is also important, as it releases water slowly, increases nutrient status, improves the soil physical condition, facilitating optimum crop growth that leading to higher water productivity and yield.

2.2.2 Puddled Soil

It is a major reason of deteriorating physical properties of soil especially destroying soil aggregates and decrease infiltration rates/water transmission in soil. It is, nevertheless, frequently used in rice-growing areas in eastern countries. Though the method may benefit rice growth in some cases, it has the potential to have serious negative consequences not just for soil health but also for crop development and yields. The system's main drawbacks are: (i) a high water need, (ii) deterioration of soil aggregate and structure, which negatively impacts succeeding upland crops, and (iii) a restriction on root growth in the soil profile. The deterioration of the soil structure caused by puddling is one of the reasons for the diminishing productivity of the rice-wheat cropping system in portions of the Indo-Gangetic plains (IGPs). Puddling, on the other hand, can aid in the removal of salts from the root zone under some circumstances. As a result, it's critical to look for alternatives to puddling (e.g., dry sowing/direct seeded rice), especially in areas where water is scarce. Low SOC status in the soil is one of the key causes of degrading soil physical qualities in the areas. The rapid rate of oxidation of organic materials causes this disease. Despite the high rate of decomposition, adequate land use and adoption of best management practises (BMPs)/recommended management practises (RMPs) specific to the location might enhance the SOC content of these soils. Low levels of SOC content have been recorded as a result of minimal or little crop residue addition, low application of farmyard manure, and widespread use of slash-and-burn agriculture.

2.2.3 Waterlogged Soils

Waterlogged area is due to abstraction or runoff water overland surface or due to drainage congestion. Bihar plains (agrocliamtic zone II specially) are said to have 20.3% soils suffering from poor drainage and 21.5% with imperfect drainage. Imperfect escape of various canals left over haphazardly is accentuating the waterlogging. Deep water paddy, chestnut and makhana cultivation may successfully be done in these soils. Pisciculture can also be suggested for these problematic areas.

Management options

i. Levelling all the canal irrigated lands.
ii. Formation of separate drainage channels other than irrigation channels.
iii. Construction of percolation tanks or small ponds.
iv. Afforestation in wasteland will bring down the wastage of excess water.
v. Increasing the carrying capacity of irrigation channels by widening and strengthening.
vi. Clearing water obstructions.
vii. Desilting of ponds, tanks, lakes and channels in a regular interval.

2.2.4 Calcareous Soils

These soils contain high $CaCO_3$ content, coarse in texture, high pH (8.0 to 8.5) and high P-fixing capacity. The calcareous soils have developed on the alluvium of the Gandak river with high content of free calcium carbonate ranging from 10 to 40%, evenly distributed throughout the depth of the profile. These soils are light coloured, pale brown to yellowish brown. Their texture varies from sandy loam to loamy sand, and the pH is mainly alkaline in nature. Remedial measures like: i) adjustment between soil moisture, soil pH and organic matter needs to be maintained to render the unavailable P into the available form To avoid soil P deficiency ii) the best method to increase the availability of plant nutrients is to increase the CO_2 pressure by planting, application of bulky organic manures and green manures.

2.2.5 High Bulk Density Layer Soils

These soils have developed on alluvial plains receiving fine sediments from the back water of river Ganges. The pan like structure and high bulk density has been developed in many soils due to introduction of paddy cultivation. These soils crack heavily on drying. The cracks are 5-8 cm wide and 60-120 cm deep. These soils are found in the districts of Shahabad, Patna, Gaya, Munger and Bhagalpur.

Management: Use of green manuring with dhaincha (*Sesbania rostrata*) in *kharif* along with the application of 5 t ha^{-1} rice husk has been found very beneficial in improving soil physical condition and yield of paddy and subsequent crop of wheat.

2.2.6 Eroded Soils

Soil erosion is a major soil constraint for agriculture in some parts of the eastern region. The some of the districts of Bihar e.g., Banka, Jamui, Nawada, gaya, Aurangabad, Rohtas and Kaimur are facing the problem of soil erosion.

Management: The effective soil and water conservation measures are contour bunds, grassed water way, water harvesting tanks, gully control structure, contour trenches, construction of silt detention dams and other agronomic practices such as cropping systems, crop geometry, contour cultivation, strip cropping, mulching, low intensity tillage, agroforestry, and growing of grasses etc. Based on micro-watershed approach, the adoption of diversified cropping systems such as agri-horticulture and agri-horti-silvi-pastoral are certainly few better options for judicious conservation of resources.

3. Effect of Climate resilient technologies on Soil health and Carbon sequestration

Climate resilient technologies involve practices such as use of precision farming techniques (laser levelling, site-specific nutrient application), high yielding hybrids, retention of residues, increased plant populations, multifunctional landscape management and conservation tillage. These practices could help to reduce the negative environmental impacts on agriculture through improvement in soil health and increased carbon stock in the soil system. There is a good potential to put 2-3 m ha area under conservation agriculture (CA) in eastern India. However, agricultural intensification in India resulted in carbon-sequestration of about 12.7-16.5 Tg yr^{-1}. Besides organic carbon sequestration, there is a possibility of sequestration of secondary inorganic carbonates, particularly in irrigated areas, at about 21.8-25.6 Tg C yr^{-1} (Manna et al. 2012). The total potential of a soil organic carbon sequestration in India of about 77.9 to 106.4 Tg yr^{-1} (Lal, 1989).

Rice based cropping systems affected soil health in terms of pH, EC, SOC, available P, available K and total N. Mandal et al (2006) in thirty-three years' long-term study on nine predominant rice-based cropping systems in sandy clay loam soils of West Bengal, noticed that decrease in soil pH in long flooded rice soils. This is attributed due to rhizosphere acidification and changes in the CO_2 equilibrium in soil-solution at root zone (Kirk, 2004). Similarly, rice cultivation generally resulted in lowering of EC irrespective of season of its cultivation and cropping systems (Mandal et al. 2006). They further emphasised that SOC, total soil N and available P increased in jute-potato-rice, jute-rice-rice, rice-potato-rice, and rice-potato-sesame, but decreased in rice-rice, rice-wheat, and rice-rapeseed-rice. Rice-wheat, rice-rice and rice-rapeseed-rice cropping systems registered decrease in available soil K while jute-potato-rice cropping system only recorded an increase in available soil K content. In other rice-based cropping systems, the content of available soil K was remained unchanged after three annual cropping cycles because of high removal of K-rich vegetative biomass in those intensive systems. Rice-rice and rice-wheat cropping systems have shown decline in organic carbon content which raises a concern about the sustainability of these rice-based cropping systems which would further affect the food security in the Indo-Gangetic Plains. The decrease in organic carbon content under most of the rice-based cropping system was mainly due to lesser use of FYM, prevailing practice of continuous cropping, removal of crop residues and excessive tillage in southeast Asia (Nambiar, 1994; Yadvinder-Singh et al., 2005).

4. Soil Management techniques for enhancing crop productivity and soil health

4.1 Integrated nutrient management

Introduction of genotypes of higher yield potential coupled with precise nutrient management have been focused for enhancing the rice productivity in most of the policy and research programmes in last 7 decades. Inorganic fertilizer is key drivers to enhance the rice productivity. However, in past few decades, rice productivity has stagnated or decreased despite of application of higher rate of chemical fertilizers (Zhang et al. 2012). Recognizing the issues integrating organic and inorganic fertilizers management strategies has been promoted to capture the potential of hybrid rice to increase the production and productivity (Shirale et al. 2021). In recent field experiments conducted by Mondal et al. (2015) have reported that integrated nutrient management could lead to significantly higher rice yield and at the same time substantially reducing the consumption of chemical fertilizers.

4.2 Adoption of improved crop establishment methods

Climate change has had a severe impact on lowland rice production systems, resulting in decreased yields, especially when rainfall is inconsistent or low. Four different methods of crop establishment were investigated by Sarangi, et al., (2019) which took into consideration non-puddled transplanting (NPTR), conventional puddled transplanting (PTR), drum seeding of pre-germinated seeds, and dry direct seeding (DSR). The analysis of this investigation showed that DSR method stands out in its assistance in rice establishment in submerged conditions, though drum-seeding rice was

Sarangi et al. (2019) investigated four crop establishment methods: conventional puddled transplanting (PTR), non-puddled transplanting (NPTR), drum seeding of pre-germinated seeds, and dry direct seeding (DSR), and discovered that DSR treatment assisted in rice establishment in submerged conditions, whereas drum-seeding rice was discovered to be ineffective for *kharif* season rice.. According to Singh and Chakraborti (2018), rice SRI and integrated crop management (ICM) systems produced good yields (Table 1) while using less water. In SRI, 1498 litres of water was required to produce one kilogram of rice, 1535 litres in ICM, and 1883 litres in CRC. In comparison to the transplanted CRC strategy, the ICM and SRI approaches utilised less fertiliser (Table 1). The crop establishment method, soil-water regime and integrated nutrient management (INM) strategies all had a significant influence on rice sustainability yield metrics (85–99 percent) under this climatic scenario.

Table 2. Effect of different crop establishment strategies on rice yield

Stand establishment method	Straw yield (q/ha)	Grain yield (q/ha)
SRI	62.4	49.90

ICM	70.9	52.72
CRC	56.7	44.67
C.D. ($P< 0.05$)	4.00	1.20

4.3 Conservation agriculture (CA) practices vis-à-vis climate change adaptation strategy

CA has a number of advantages, including increased biodiversity, labour savings, improves the soil human health and the environment, climate adaptation, increased crop yields and revenues, and lower costs somewhere at global, regional, local, and farm stages (Jayaraman et al. 2021). Despite the fact that the Eastern area is rich in natural resources, its potential for enhancing agricultural production, poverty reduction, and livelihood enhancement has not been realised. The second Green Revolution has been centred on the eastern part of India in order to meet the country's ever-increasing food needs. However, it is only possible if soil health is improved, biotic stresses are reduced, water productivity is increased, appropriate cultivars are developed, and land management is integrated. Conservation agriculture is so critical, particularly in the eastern IGP, where rice-wheat farming is the norm. As a result, conservation tillage (i.e., zero tillage and bed planting) in combination with other complementing strategies like as soil cover and crop variety has emerged as a viable option for ensuring long-term food supply while maintaining environmental integrity. Zero tillage enhances soil moisture retention, minimises soil temperature changes, reduces wind and water erosion, increases organic matter content in soil over time, improves soil microbial activity, and eventually leads to improved crop development and output (Gathala et al. 2011; Kumari et al. 2020; Jayaraman et al. 2021). Traditional rice-wheat systems are well-known for emitting methane and nitrous oxide into the atmosphere, whereas CA-based rice-wheat systems reduce these emissions by creating a more aerobic soil environment. Because burning rice straw in a typical system releases 70% CO_2, 7% CO, 0.66 percent CH_4, and 2.09 percent N_2O, using a CA-based system with its residue retention principle reduces GHG and other pollutant emissions to the environment (Gupta et al. 2004). Switching all croplands to reduced tillage may sequester 25 Gt CO_2, or 1,833 Mt CO_2-eq/yr, during the next 50 years, rendering conservation tillage among the most important options for stabilising worldwide GHG emissions from any sector (Baker et al. 2007).

4.4 Management of degraded soils

4.4.1 Acidic soils

Assam, along with other north-eastern states, West Bengal, Bihar, Odisha, Andhra Pradesh, Kerala, Madhya Pradesh, Karnataka, Maharashtra, and Tamil Nadu are also affected by acid soils (Maji et al. 2008). Cultivating acid-tolerant crops and cultivars/varieties and replenishing nutrients through proper carriers are all part of acid soil management, as are water management and other agronomic practises.

4.4.2 Salt affected soils

Salt-affected soils in India are categorised into two types: sodic (alkali) soils and saline soils. A chemical amendment-based approach has been developed to rehabilitate alkali/sodic soils. Field levelling, bunding, ideal soil sampling methods to determine sodicity status for calculating amendment dose, application of gypsum/pyrite as needed and mixed in upper 10 cm of soil, keeping water ponding for 5-7 days, following a rice-wheat rotation for three to four years, and growing sesbania as a green manure crop after wheat harvest in April are among the technology's components (Sharma and Chaudari, 2012; Singh 2019). The use of slat tolerant crops is recommended for the management of salty soil drainage, especially subsurface drainage (Datta et al. 2000; Manjunatha et al, 2004). A recently developed technique to manage waterlogged areas is the bio-drainage technique, which involves reducing groundwater resources in waterlogged areas by using rising tree plantings. This method makes use of solar energy to remove excess soil moisture content through the process of tree transpiration. It is a form of preventive measure utilised in canal command regions to prevent the development of salt and waterlogging difficulties. The method works well while soils are being salinized as a consequence of elevated ground water levels. If the soils already are salinized, however, its use is restricted. The potential of several tree species to transpire water from varied salinity water table depths has been investigated. Eucalyptus, Populus, Casuarina, and Bambusa have been recognised as the most promising plants for bio-drainage.

4.5 Site-specific nutrient management and the use of a soil health card

The soil health card (SHC) contains crop-specific recommendations for nutrients/fertilizers needed for farms, allowing farmers to increase production by applying suitable inputs. Nutrient usage efficiency is low under present management approaches, and farmers frequently fail to apply nitrogen, phosphorus, and potash in the correct ratio to satisfy crop needs. Site-specific nutrient management (SSNM) is a method of giving nutrients to crops only when they are needed. The SSNM reduces fertiliser waste by limiting high fertiliser rates and eliminating fertiliser application when the crop does not require nutrient inputs.

5. Strategies and approaches for climate resilience

5.1 Soil and Climate change

The soils of the eastern region are not as well in order to ensure food security. As a result of the rapid changing climatic conditions in these areas, numerous floods and droughts occur, weakening the physical, chemical, and biological qualities of soil. The poor fertility level of the soil prevents it from sequestering the required quantity of carbon from the atmosphere. Since a result, large-scale cultivation of forage and fuel-producing crops is required to combat climate change, as it is the most pressing requirement of the hour. In addition, the region's agroforestry project must be expanded in order to capture atmospheric CO_2 and convert it to humus through the soil C sequestration mechanism. Global soils have a carbon sink capacity of roughly 1 Pg C Yr-1, that could counter 0.47 ppm of CO_2 rise in the atmosphere per year. Because soil is a bio-membrane that screens and denatures pollutants, enhancing the C pool inside the soil is also vital for improving water quality. Soil quality restoration improves the quantity and quality of water resources in a watershed. Soil carbon sequestration is a win-win situation.

5.2 Water management and Plant Performance in a Changing Climate

Any major shift or variable in temperature, precipitation, humidity, light, or wind is referred to as climate change. These alterations may be of very brief duration or may endure for decades or more.

The need for research on the consequences of climate change on water management and its impact on plant response is urgent. Efforts must be made to examine the issues confronting the agriculture industry in light of a rapidly rising population and economic development in a changing climate. Scientists and policymakers are concerned about the effects of climate change on agriculture, soil, and water supplies.

As the climate changes over the next few decades or centuries, agricultural soil and water availability (amount and quality) will remain critical components for long-term agricultural output.

To deal with climate change, many agricultural regions will need to employ adaptive water-stress-resolution measures.

- Use of drought-tolerant and drought-resistant crops;
- Changes in agricultural land use and management practises, such as soil cultivation, fertilisation, planting techniques, planting and harvesting times;
- Implementation of WUE measures;
- Increased use of recycled and low-quality water for irrigation; and
- Development of practical tools for irrigation scheduling and measuring plant water stress.
- **Table 3.** Suitable measures for drought management

Rainfall pattern	Management options
A. Late onset of monsoon	(a) Transplanting of alternative crops and varieties
B. Prolonged dry spells	
(1) Immediately after sowing	(a) Resowing of crops
	(b) Reduce plant population

(2) Mid-season 'breaks'	(a) Remove the sensitive crop component in mixed stand. (b) Mulching (c) Land configuration for in-situ moisture conservation (d) Weed control (e) Intercropping (f) *Ex-situ* harvesting and recycling of rain water
C. Early cessation of rains	(a) Reduce plant population (b) Protective irrigation (c) Mulching (d) Defoliation of lower leaves.

6. Conclusion

Climate resilient agriculture (CRA) enables agricultural communities adapt to climate change while simultaneously sustaining crop yield and also contributes to mitigation of adverse effects by adopting suitable practices, developing policies and institutions and creating needed finances. The CRA is a unique strategy to manage landscapes, including crops, livestock, forests, and fisheries, that addresses the associated concerns of food security and climate change. CRA strives to address many positive objectives at the same time, such as higher production, increased resilience, food and nutritional security, livelihood security, and lower emissions. The CRA also strengthens food and nutritional security and delivers environmental benefits. Moreover, CRA technologies such as use of precision agriculture (laser levelling, site-specific nutrient application, precise water application/ management), high yielding crop varieties, crop residue addition (i.e. retention/ incorporation/in-situ recycling), increased plant populations, multifunctional landscape management and sustainable soil management practices (conservation tillage/regenerative agriculture/conservation agriculture) need to be adopted for higher crop productivity and better farm income. However, technologies developed but not adopted by farmers need to be refined and re-assessed in fields for better adoptability and income generation. Proper institutional mechanisms need to be built up and a community/group approach may be followed in transfer of technology. Besides, use of information technology (IT) /and information communication technology (ICT) be strengthened and promoted for faster dissemination of farmer-friendly technologies.

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Chapter 10

Farm Mechanization of Rice Cultivation

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Abstract

Mechanization of agricultural production is evitable for reduction of cost and labour and increasing productivity. Rice cultivation is labour and energy intensive which cause higher cost of production. Although rice cultivation in India is considered one of the mechanized crop production processes there is still some scope of improvement, especially in transplanting and plant protection operations. In India, the extent of mechanization for various farm operations are reported to be 40% for tillage, 30% for seeding/planting, 37% for irrigation, 48 % for threshing, and 35% for plant protection. This chapter provides an overview of mechanizations status along with various farm implements and machines available for different operations in rice cultivation in India. Further, the carbon footprint due to use of farm machineries has also been discussed in this chapter.

Keywords: Rice mechanization, farm machinery, precision farming, soft computing, climate- resilient farm machinery

1. Introduction

Sustainable agricultural mechanization can also contribute significantly to the development of value chains and food systems as it has the potential to render postharvest, processing and marketing activities and functions more efficient, effective and environmentally friendly (FAO 2022). Currently, global rice output has reached 500 MT milled rice, which feeds 4.0billion people, while India's production has reached 112 MT milled rice, which feeds 0.8 billion people, or 65 percent of the country's population (Pathak 2020; Guru et al. 2018a). In the previous five decades, Indian agriculture has made remarkable improvement in improved plant variety, farm mechanization, irrigation and drainage technologies, food processing and soil health management. However, stagnant net sown area, decreased per capita land availability, climate change, and soil degradation all have posed severe constraints in recent years. Rapid population growth is putting enormous strain on Indian agriculture, which must produce enough food and fiber in sustainable way in order to achieve nutritional security in near future. The average size of land holding is also shrinking which is restricting use of large size of machineries. According to Patel et al. (2018), the average land holding size is currently 0.68 ha which will shrink further to 0.32 ha by 2030. With all of these obstacles, India is a growing country with the task of providing food security for the world's most populated country by 2050.

Farm mechanization can help both large and small-scale farmers to address these difficulties. Inputs are measured and distributed efficiently to raise land productivity, reduce crop losses, and improve agro-product quality. Labor saving and drudgery reducing equipments increase labour productivity. International and national researches have shown that engineering inputs can raise productivity by 15%, reduce production costs by 20%, increase cropping intensity by 20%, and reduce drudgery by 20% (Guru et al. 2018a). Thus mechanization plays the most significant role in sustainable agricultural production as well as balanced ecosystem.

Growing rice in conventional and traditional ways necessitates a greater and more uneven distribution of inputs, which has a negative impact on the environment and affects rice yield and profitability. In this chapter, present status of various equipments and machineries available for different operations in rice cultivations has been discussed. The carbon footprint for use of farm machinery has also been highlighted. With the use of efficient and hi-tech machineries rice cultivation system can be made sustainable in terms of energy and cost inputs.

2. Mechanization status of rice cultivation

Rice is predominantly grown with labour-intensive farming techniques, and its production and processing employs about half of the labour population in South and Southeast Asian countries. By minimizing turnaround time, enhancing timeliness of operations, and boosting cropping intensities, agricultural mechanization aids in improving land and labour productivity. As a result of the requirement to harness available moisture during tillage and planting in drier locations, agricultural machinery has increased. Farm machines like the rotary tillers (popularly known as 'rotavator' in India), ferti-seed-drill, raised bed planter, and laser leveller increase efficiency while using less water/moisture, boosting productivity in dryland areas.

Mechanization level: This is a quantitative index of mechanical agronomic activity, calculated by dividing the area under automated agriculture by the total area under cultivation. This index is used to calculate the ratio of mechanized operations at various phases of agriculture. Individual crops and specific operations' mechanization levels are frequently estimated separately (Lak and

Almassi 2011):

$ML=A_M/A_C$

Where: ML =mechanization level (%); A_M = mechanized cultivated area (ha); A_C = total cultivated area (ha).

Mechanization requirement: This index was computed using a simple mathematical relationship of 100 minus the level of mechanization for each agronomical operation (Khambalkar et al. 2010; Zangeneh et al. 2010).

$MR=100-ML$

Where: MR= mechanization requirement (%); ML= mechanization level (%)

In 2020-21, mechanical power accounted for 74.42 percent of total available power of 386.576 million KW. Mobile power has a significant impact on the country's food grain productivity. In 2020-21, the power availability was 2.761 kW/ha. The power availability per ha from tractor, power tiller, diesel engine, electric motor, animal, and human was 1.64kW (59.38%), 0.03kW (1.02%), 0.39kW (14.028%), 0.54kW (19.57%), 0.084kW (3.025%), and 0.080kW (2.98%), respectively (Singh and Singh, 2021).

Farmers like the idea of harvesting wheat, paddy, and soybean together. In India, mechanization levels for various farm operations are reported to be 40% for tillage, 30% for seeding/planting, 37% for irrigation, and 48 % for wheat threshing, 5% for other crops threshing, and 35% for plant protection (Guru et al. 2018a).

The use of machinery for field preparation operations for rice production is common in India, with the majority of farmers using tractors with deep ploughing and puddling implements. However, the following processes, including as seeding, transplanting, harvesting, and threshing, are all done by hand with very little mechanization (Tiwari 2021). Farm power has transitioned rapidly from animal to mechanical power in recent years. Mechanical power speeds up farm operations and lowers the labour cost and other expenses, while limiting animal use on farms exacerbates crop biomass burning. In farm production activities, mechanization also helps to reduce drudgery.

2.1 Gender-neutral farm machineries

Mechanization refers to the agricultural process of replacing manual labour or use of draught animals with machinery. The impact of mechanization on men and women is very important to ensure that both men and women will benefit and neither will be harmed. As per last census in 2011, the share of female work force in Indian agriculture is 37% and would be increasing in the coming years. Therefore, gender neutral agricultural machineries are inevitable for sustainable mechanization. A considerable work has been done by Central Institute of Agricultural Engineering, Bhopal on collection and analyses of anthropometric data on women workers of India which greatly helped in designing workplace, tools and equipments for women. Design modifications on some important parts of equipments have been carried out to make them gender neutral. A seed treatment drum of 200 kg capacity has been developed to avoid exposure to harmful chemicals. Height of operation and handle configuration in cono weeder and manual seeder were modified to suit women anthropometry. Three row walk behind type transplanter can also be operate by a women worker to avoid bending posture during transplanting. The local sickle design has been improved to naveen sickle for easy operation. Pedal operated thresher is light weight and less thrust consuming and suitable for women worker to operate with ease. Hand operated fan type winnower is gender neutral and very useful in saving labour and time for winnowing operation (Mehta et al. 2018). Small scale motor powered multi-crop thresher of lower capacity has been developed women friendly by AICRP scheme of ICAR.

3. Machinery for field preparation

Mould board plough, cultivator, disc harrows are used for tillage operation. The rotavator is getting prominence due to its ability to perform multiple operations at the same time. Savings of 60-70% in operational time and 55-65 % in fuel consumption with a single operation of rotavator have been observed when compared to the traditional seed bed preparation procedure of ploughing and harrowing separately, in addition to moisture conservation due to capillary destruction. Apart from this, details of various field preparation machinery are presented in this section.

3.1 Laser-assisted land levelling

Fields that are properly levelled are essential for good crop establishment, water management, weed control, and an evenly ripening crop that ensures high yields and quality. Laser aided land levelling achieves great accuracy with only a +/- 10 mm difference in height, resulting in water savings of 40-60%, yield increases of 10-15%, reduced pesticide use, and even modestly improved grain quality. As a result, rice production costs are reduced dramatically, and better water management can ensure to reduce greenhouse gas emissions (www.irri.org).

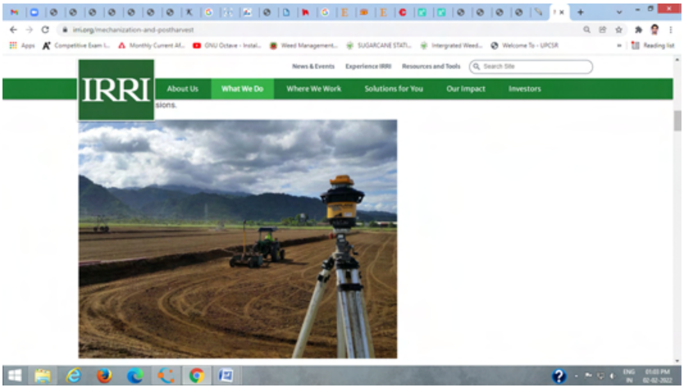

Figure 1. Laser-assisted land leveling (irri.org)

3.2 Puddlers

Ploughs, comb harrows, patella puddlers, ladder puddlers, and rotary puddlers are examples of animal or tractor-drawn implements used for puddling. It is usually done after the field has been ploughed and there is roughly 50 to 100 mm of standing water. The amount of puddling, on the other hand, is determined by the type of puddler and the level of puddling. Because the circular motion of rotary puddiers modifies the direction of shear stress, it matches the weakest fracture plane within a clod better than ploughing. Furthermore, when compared to ploughs, rotating puddlers compact the subsoil, chop and press organic debris, and require a lower draught (source: farmer.gov.in).

3.3 Disc type puddler

It is a puddling implement pulled by a bullock. It is divided into two gangs, each having three plane discs put on top of a hollow drum. The capacity of its field is 0.4 ha/hour. Two float-harrow operations are all that is required to prepare the field for seedling transplanting. The time necessary for puddling has been reduced from 42 hours in the case of indigenous plough to 11 hours (source: icar-nrri.in).

Figure 2. Disc type puddler (source: www. indiamart.com)

3.4 Tractor-operated lug wheel puddler

For mechanized rice transplanting, high-speed shallow puddling of rice fields with a higher amount of soil dispersion is necessary. The depth of the puddling is kept short (130 mm) to allow for more soil dispersion (48.6%). The effective field capacity is 2.5–3 ha/day, and the field is ready for transplanting in a single pass, compared to 3–4 passes for the peg type puddler, which is commonly employed by farmers and has an average coverage of 1 ha/day (source: icar.org.in).

that with the tractor-operated lug wheel puddler the depth of puddling was maintained shallow (130 mm) with higher amount of soil dispersion (48.6%). The effective field capacity was found

Tractor-operated lug wheel puddler for high speed shallow puddling of rice fields

straw left after combining and for chopping into pieces fc spreading in the field

- High capacity groundnut thresher selected for feasibili testing gave cleaning and threshing efficiency ranged fro 96.1 to 99.4% and 97.8 to 99.4%, respectively
- For sowing small seeds like sesame, cumber and sorghun power-tiller-operated air-assisted seed drill developed

in the quantity of seeds dropped from different seed metering was within the limit of 5%.

During field trials, three rows of soybean and two row pigeonpea at 300 mm row-to-row spacing were sown on b beds with 1.55 m top width and 1.85 m bed-to-bed spacing. Ave depth of sowing was 83 mm. The field capacity of planter 0.418 ha/h with an effective width of coverage of 1.85 m. efficiency was 64.2%.

Figure 3. Tractor-operated operated lug wheel puddler (www.icar.org.in)

4. Machinery for sowing and transplanting

Due to labour shortages, farmers have shifted from manual transplanting to broadcasting of seeds, which necessitates the high seed rates, results in uneven crop establishment, and impedes mechanical weed control. As a result, promotion of mechanized crop establishment options such as mechanical transplanting and various direct seeding options for wet and dry seeding is being done. Simple implements such as the drum seeder are included, as are more complex implements such as the power tiller or four-wheel tractor drawn implements. A few of them are listed below:

4.1 One row manual seed drill

This is ideal for dry paddy seed sowing with 20-cm row spacing. Its field capacity is 0.008 to 0.01 ha/ h (icar-nrri.in).

4.2 Two row manual seed drill

This seed drill is pulled by hand and ideal for dry paddy seed sowing with 20-cm row spacing. It has cup type seed metering mechanism. Its field capacity is 0.019 to 0.022 ha/h (icar-nrri.in).

4.3 Three row manual seed drill

It is attached with fluted roller type seed metering system and ideal for dry paddy seed sowing with 20-cm row spacing. It can give 0.03-0.04 ha/h field capacity (icar-nrri.in).

4.4 Eight row manual drum seeder

Its cylindrical shape is ideal for spreading sprouted paddy seed in puddled fields with 20-cm row spacing. Its field capacity is 0.037 to 0.04 ha/hour and cost is Rs.

6500 per unit. When compared to broadcast seeding, it reduced seed rate by 35-40% and weeding costs by roughly 55% (icar-nrri.in).

Figure 4. Eight row drum seeder (ksnmdrip.com)

4.5 Power tiller operated seed drill

It is a five-row seed drill with a seed metering system constructed of plastic wheels with grooves all the way around. It's ideal for planting rice and groundnuts in the dry season. It has 25 cm row to row spacing. The field capacity of the equipment is 0.15 ha/ h (icar-nrri.in).

4.6 Self-propelled eight row hill seeder

It is an eight-row paddy seeder with an engine. It's ideal for spreading sprouted paddy seeds in puddled field with 20-cm row spacing. It can produce 0.23-0.25 ha/ h in the field. Because it avoids nursery growing, it has cost and operational advantages (icar-nrri.in).

4.7 NRRI four row manual rice transplanter

It can be used to transplant mat type rice seedlings that are 20-25 days old. The row to row spacing is maintained at 24 cm. It can produce 0.018-0.020 ha/ h in the field. It reduces the amount of labour required by 30-40% and the cost of transplanting by 40% (icar-nrri.in).

4.8 Two row transplanter

This gender-friendly technology saves 40-45 percent in labour when compared to hand transplanting, and females can easily use it. It has a field capacity of 0.02 ha h-1 (Guru et al., 2018).

4.9 Four row transplanter

This causes saving in labour by 55-60 % as compared to manual transplanting. It has a field capacity of 0.03 ha/h (Guru et al., 2018)

4.10 Self-propelled Rice Transplanter

It is a riding type machine with a single wheel drive and a diesel engine. In a single pass, it transplants seedlings from a mat type nursery in eight rows. With the help of five people and a speed of 1.1-1.5 km/hour, it can transplant 1.2-1.5 ha every day. When compared to manual transplanting, it saves roughly 65% labour and 40% operational costs. Self-propelled walking transplanters with four rows and six/eight rows of four wheels motorized riding transplanters are also commercially available (source: aicrp.icar.gov.in).

Figure 5. Self-propelled Rice Transplanter (www.aicrp.icar.gov.in)

5. Machinery for soil fertilization and plant protection

Plant protection plays an important role in meeting crop production targets. Chemicals are typically applied in the fields using plant protection equipment such as broadcasters, dusters, and sprayers. Different types of equipment used in plant protection are described below:

5.1 Drop-type or full-width-feed broadcasters

Drop-type broadcasters are typically 2.4–3.7 m wide pull-type tools, although they are also available as mounted units and attachments for a variety of open-field tillage equipment. Metering devices are spaced at regular intervals of around 150 mm throughout the whole length of the hopper. This sort of implement is useful for spreading fertilizer or lime. Furrow openers are available for band installation below the soil surface, and by sealing part of the outlets, they can be utilised for side-dressing in row crops (Krishnan 2001).

5.2 Knapsack hand compression sprayer

Row crops, nursery stocks, and shrubs can all be sprayed with this sprayer. The pressure produced by these sprayers varies depending on the pump and ranges from 3 to 12 kg/cm^2, which is higher than the pressure produced by a manual compression sprayer. In most circumstances, however, a pressure of 3-4 kg/cm2 can be maintained with little effort, and coverage is 0.5-1.0 ha/day (source: www.hillagric.ac.in).

5.3 Motorized knapsack sprayer

A machine-generated air current propels the spray liquid out of the machine. At the nozzle, they deliver 6.8 to 42.5 m^3 of air / min at 200-420 km/hour. The tank has 10-12 litre capacity. It is driven by 1.2–3.0 hp petrol engine, and working pressures below 1.5 kg/cm2 is not recommended because the nozzle does not work properly (source: www.hillagric.ac.in).

5.4 Motorized knapsack mist blower cum duster

Two plastic tanks (fuel and water/dust), a 2-stroke petrol/kerosene engine (35 cc), a centrifugal fan, a pump, a spray hose, a rope starter, a delivery pipe, a cut-off cock, shoulder straps, and a frame are the main parts of the blower cum duster. The fan creates a high-velocity air stream when the engine rotates. The spray control valve is gradually opened and adjusted for the optimum flow rate. The discharge hose is directed to the target by the operator. It can be used for dusting as well as ULV applications. Field capacity is 2-3 ha/hour. Petrol or petrol/kerosene engine of 1.2 hp is required to operate the equipment (source: farmech.dac.gov.in).

5.5 Self-propelled light weight boom sprayer

A 3.75 kW diesel engine powers the unit. A 100-liter tank, a roller-type spray pump, and a boom with 12 nozzles make up the spray unit. The nozzle spacing is retained at 500 mm, however it can be modified to suit various nozzle types and applications. It has a paddy field capacity of 0.6-0.8 ha/hour and a forward speed of 1.2-1.6 km/hour. There is 500 mm of ground clearance. The spraying boom has been installed on the power unit via a canopy frame in such a way that spraying takes place behind the operator, avoiding contact with the spray solution (source: aicrp.icar.gov.in).

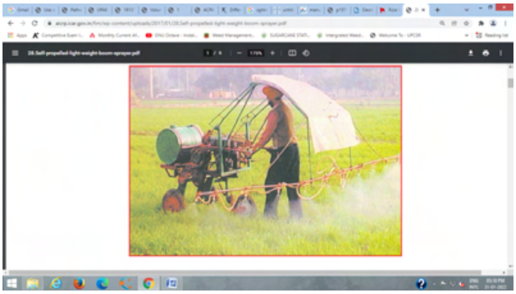

Figure 6. Self-propelled light weight boom sprayer (Source: www.icar.gov.in)

5.6 Drone Spraying

Drones can carry chemical-filled reservoirs of appropriate capacity to spray crops across huge areas in less time. A self-contained and pre-programmed operation on precise times and routes ensures that crop spraying is far safer and more cost-effective than other methods. In order to provide uniform and optimal spraying results across various topography, they are designed to use ultrasonic echoes, time of flight lasers, and global navigation satellite systems to self-adjust their altitude and speed. Drones are used by smart farms to spray agricultural chemicals thereby reducing human exposure to toxins. Also unrivalled in automated spot treatment using stress detection technology, drones are able to work on the unhealthy areas while leaving the healthy ones alone. In comparison to traditional equipment, drones can enhance spraying capacity by up to five times (source: www.niam.res.in).

Figure 7. Drone spraying (source: www.dronefromchina.com)

5.7 Aircraft fertilization

In some regions, fertilizers are distributed by aeroplane, notably on rice and minor crops, as well as mountainous pastures. When huge regions are involved, it is impracticable to complete the work with ground equipment, aircraft fertilization is most likely to be used.

6. Machinery for weeding

Weed control is an important practice in paddy fields to prevent yield losses. It should be noted that mechanised rice weeding is technically dependent on transplant mechanisation. Before mechanising the rice weeding operation, the planting process should be mechanised. Some weeding tools used in rice cultivation are described below.

6.1 Wheel finger weeder

It's a manual weeder that pulls and pushes. A frame, a wheel, a handle, and five curved fingers make up the weeder. The distance between fingers can be adjusted.

The fingers dig into the soil and loosen it as the operator pushes the handle back and forth, uprooting the weeds. This implement has a field capacity of 0.022-0.025 ha/ha. In comparison to hand weeding, it also saves 40-50 % labour (icar-nrri.in).

6.2 Star-Cono-Weeder

In wet fields, it is ideal for weeding, churning, and mulching. It has a cutting width of 10-15 cm. The weeds are sliced and churned into the soil by the stars and conical drums. It was determined to be ergonomically acceptable for local labour and reduced labour requirements by 50-75 %. It can produce 0.013-0.017 ha/h in the field. In system of rice intensification, the Conoweeder can be utilised extensively (icar-nrri.in).

Figure 8. Cono-Weeder (source: www.engineeringforchange.org)

6.3 Single row power weeder

It is particularly well suited for upland rice intercultural activities. There are several components to the machine, including an engine mounting frame, the main frame, the transmission system, a jaw type clutch assembly, a clutch control lever, a handle, two transport wheels with rotating tine assemblies attached, a support wheel with a rubber flap. It can produce 0.022 ha/hour in the field. When compared to manual weeding, there is a 50-55 % labour savings (source: icar-nrri.in).

7. Machinery for harvesting and threshing

Contract harvesting is becoming a popular business in Asia. It is possible to harvest japonica rice with the head-feeder type that is often employed in East Asia. The traditional style of combine harvester is widespread in south and southeast Asia, and it is well suited for harvesting Indian rice crops. Some harvesting and threshing machines are listed below.

7.1 Power Tiller Operated Vertical Conveyor Reaper

It is a walk-behind type reaper windrower with a motorised tiller installed on the front that is perfect for harvesting and windrowing upright rice crops. The reaping attachment is made up of a cutter bar, two crop conveyor belts, crop row dividers, and star wheels, among other things. The engine drives the cutter bar and conveyor belts via a belt-pulley and a safety clutch. The effective field capacity is 0.16-0.20 ha/h (aicrp.icar.gov.in).

7.2 Self-Propelled Vertical Conveyor Reaper

It is a walk-behind harvester powered by an engine. Through belt-pulleys, engine power is transferred to the cutting bar and conveyor belts. Crop row dividers separate the crop as the reaper moves forward, and the crop comes into touch with the cutter bar, which shears the crop stems. The lugged conveyor belt transports the chopped crop to one side of the machine, where it is manually packed and transferred to the threshing yard. The machine's field capacity is 0.15–0.17 ha/h. When compared to the traditional method, there is a 90-95 % labour and time savings, as well as a 63 % cost saving (aicrp.icar.gov.in).

7.3 Tractor Front Mounted Vertical Conveyor Reaper

It comprises of a reciprocating cutter bar assembly with 76 mm pitch. After the crop row dividers have been mounted in front of the cutter bar assembly, the star wheels are installed over top of them. The machine is powered by the tractor's PTO. The tractor hydraulic system controls the machine's height above ground. In addition to being kept vertically and supplied to one side of the machine by lugged belt conveyors, the crop falls in the form of a windrow that is perpendicular to the machine's movement direction after being chopped by the cutter bar. The machine's field capacity is 0.4 ha/h at 2.5-3.5 km/h forward speed (aicrp.icar.gov.in).

7.4 Stripper harvester for paddy

The stripping mechanism, grain tank, hydraulic system, steering system, gear box, motor, cage wheel, and chassis are all part of it. To transport power from the gearbox to the stripper rotor, a V-belt and a set of pulleys are used. Increased forward speed lowered broken grain loss, but increased peripheral speed initially decreased and later increased. At a forward speed of 2.25 km/hour and a peripheral speed of 19.78 m/s, the harvester performs better. The paddy stripper harvester machine's average field capacity and field efficiency are 0.14 ha/hour and 69.38 %, respectively (Bhanage et al. 2017).

7.5 Sifang mini rice combine (China)

On less densely populated rice fields with minimal weeds, the Sifang combine performs admirably. In densely populated crop fields, the combine harvester should be operated at low speeds, while in sparsely populated crop fields, it should be operated at high speeds. Mechanical grain damage ranges from 1.43 % to 4.43 %. With a harvesting speed range of 0.8-4.5 km/h, the harvester's field capacities ranges from 0.10 ha/h to 0.39 ha/h and consumed up to 11 L/ha of fuel, and produced 6-9 % track slip (Amponsah 2017).

Figure 9. Sifang mini rice combine (source: www.sci-hub.ee)

7.6 Portable power operated paddy thresher

It has a threshing drum with wire loops. A 1.0 hp single phase electric motor provides rotational power to the threshing drum via a belt and pulley system. It is cost-effective and suitable for paddy threshing by small and marginal farmers. It produces 3 to 4 q/hour (icar-nrri.in).

7.7 Axial-flow paddy thresher

It comprises a threshing cylinder, concave, cylinder casing, cleaning system, and feeding chute. Crop is fed from one end and moved axially, with the straw being discharged out of the other end. The crop revolves three and a half times around the cylinder during threshing, separating all of the grains. The threshing cylinder is a peg-type threshing cylinder. The thresher's casing includes seven louvres for moving the crop axially. Cleaning the grain is done with two aspirator blowers and two sieves. It has a 35 ptohp requirement (farmech.dac.gov.in).

Features

It consists of a threshing cylinder, concave, cylinder casing, cleaning system and feeding chute. In axial flow concept, the crop is fed from one end, it moves axially and the straw is thrown out from the other end after complete threshing of the crop. During threshing, the crop rotates three and half times around the cylinder and all the grains get detached. The threshing cylinder is of peg type. The casing of the thresher has 7 louvers for moving the crop axially. Two aspirator blowers and two sieves are provided for cleaning the

Figure 9. Axial-flow paddy thresher (source: www.farmech.dac.gov.in)

7.8 Multi-crop thresher

Rasp bars, oscillating sieves, a concave, and a winnowing and cleaning attachment make up the threshing cylinder. The rasp-bar cylinder is constructed of cast iron rings, sheet metal, and toothed racks and is mounted on the main shaft, which is supported by two massive pedal bearings. This shaft is equipped with a variety of pulleys of various diameters that convey power to the winnowing and fan attachments. The machines can be adjusted for cylinder and blower speeds as well as concave clearance to thresh a variety of crops. It is equipped with a BIS-compliant safe feeding chute. It requires 7.5 hp and has a capacity of 600-1000 kg / hr (farmech.dac.gov.in).

7.9 Combine harvester

In India, China, Thailand, Vietnam and in Cambodia harvesting of paddy is done by using combine harvesters, or simply combines. It helps to deal with the labor shortage and reduces harvesting cost. It combines several operations into one: cutting the crop, feeding it into threshing mechanism, threshing, cleaning, and discharging grains into a bulk wagon. Straw is usually discharged behind the combine in a windrow. Combine harvesters can save up to 90% labour, 60% time and 5% grain loss as compared to manual harvesting (ref?).

Figure 11. Combine harvester (source: www.irri.org)

7.10 Robot Combine Harvester for Wheat and Paddy (Japan)

The combine harvester robot depended on an AGI GPS receiver and IMU for position and posture data. It is managed by the use of a CAN bus. An RTK-GPS receiver integrated with an IMU is utilised to capture the machine's position and posture. The computer in the combine harvester can determine lateral and heading error using data provided by this instrument, and then steer the machine. The initial lateral error is around 20 cm, and the early heading error is approximately

1.8 degree. (Tamaki et al. 2013).

Figure 12. Robot Combine Harvester for Wheat and Paddy (source: www.commons.wikimedia.org)

8. Carbon footprint in rice cultivation

The global warming potential (GWP) of each layer contributes to the overall carbon footprint. Pre-farm operations such as fertilizer, pesticides, machinery manufacturing, and transportation have a substantial carbon footprint. Crop types, as well as water and fertilizer requirements, have a big impact on field emissions. Because of CH_4 emissions and irrigation needs, rice crops had the largest carbon footprint of all the crops evaluated. Pandey and Agrawal (2014) have given the formula to calculate carbon footprint.

GWP of tier (kg CO_2-e ha^{-1}) = emission/removal of $CH_4 \times 25$ + emission/removal of $N_2O \times 298$ + mission/removal of CO_2

Carbon footprint =Σ (GWP of all tiers)

Carbon footprint from agriculture is calculated by the following formula (Lal 2004).

Carbon footprint = (Σ Agricultural input × GHG emission coefficients) / Grain yield.

Equipment use is expanding in response to rising population demands, and the energy delivered to machinery comes from fossil fuels, which emit greenhouse gases.

Agriculture generated around 11% (5,677 Mt CO2 eq.) of total global GHG emissions. Indian agriculture accounted for approximately 7% (403 Mt CO_2 eq.)

of global agriculture's GHG emissions (Pathak et al. 2014). In conventional tillage and no-tillage system in rice–mustard cropping, diesel contributed 19 and 6%, respectively, in total carbon footprint (Yadav et al. 2018). From India, for the period of 2000–2010, contribution of diesel in carbon footprint was estimated less than 1% by Sah and Devakumar (2018).

In terms of production, transportation, and application, fossil fuels are widely used. Rice machinery that uses fossil fuels is said to contribute 13% of China's entire carbon footprint (Zhang et al. 2017). Among the three processes, machinery was responsible for 16% of on-farm pollution. Farag et al. (2013) looked at the carbon footprint of rice production in Egypt and found that machinery was the least responsible for overall emissions.

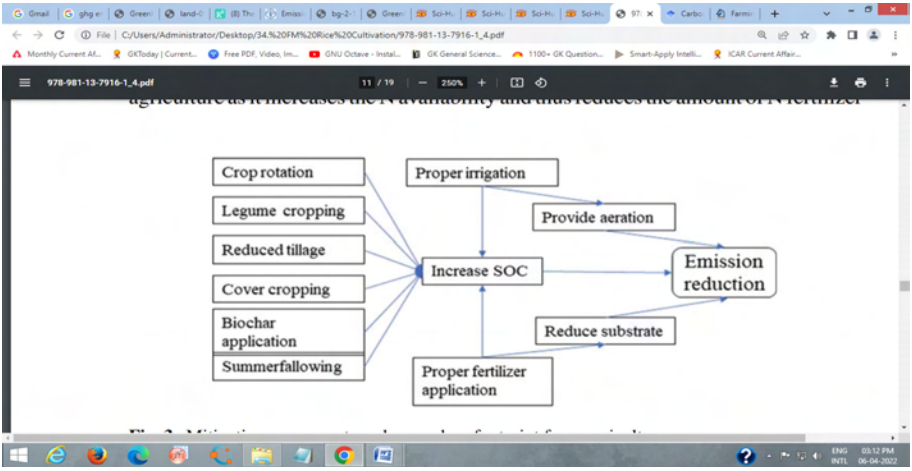

Figure 13. Mitigation techniques to reduce carbon footprint from agriculture (source: Jaiswal and Agrawal 2020)

According to Weller et al. (2015), flooded rice releases 90 percent more CH_4 than aerobic rice, but N_2O emissions are insignificantly lower not the flooded rice system. Although N_2O emissions have grown, rice fields can minimize CH_4 emissions by cycling rice with aerobic rice or maize in the dry season and rice in the wet season (Janz et al. 2019). Because maize cultivation was a weak sink for CO_2, rotation with maize reduced emissions (Janz et al. 2019; Linquist et al. 2012). Rice maize rotation also reduces the quantity of water required for irrigation, lowering the overall carbon impact.

9. Carbon footprint reduction through farm machinery

The total amount of GHGs (in terms of carbon equivalent (C-eq) emitted by agricultural processes is referred to as the carbon footprint of agriculture. Crop cultivation systems, primarily cereals, emit more GHGs than other farming systems, such as vegetables and fruits. The energy input from farm machinery, electricity, livestock management, and fossil fuels accounts for a large portion of the carbon emissions from agriculture. Agriculture-related activities such as ploughing, tilling, puddling, manuring, irrigation, a variety of crops, livestock rearing, and related equipment emit a significant amount of GHGs (Jaiswal and Agrawal 2020). The emission rates for various tillage methods are 35.3 kg CE/ha for conventional till, 7.9 kg CE/ha for chisel till or minimum till, and 5.8 kg CE/ha for no-till seedbed preparation (Lal 2004).Direct seeded rice has the greatest potential for reducing greenhouse gas emissions when compared to conventional and machine transplanted rice (Devkota 2020).Aside from that, land-use changes such as conversion of natural ecosystems to agriculture, deforestation, and crop residue burning after harvest all contribute significantly to increase carbon emissions (Jaiswal and Agrawal 2020). Tillage disturbs the soil and exposes organic matter to oxidation, resulting in SOC loss. Crop residue mulch with no-tillage increased soil carbon while also stabilizing new aggregates. Pandeyet al.(2014) discovered that reduced tillage increases the total and recalcitrant C pools in the rice-wheat system. Crop residues left in no-tillage conditions sequestered the most carbon by slowing the rate of oxidation of organic molecules. The ability of no-tillage to increase SOC is influenced by region and soil condition. India produces approximately 500 million tonnes of crop residue per year, with the north-western states producing 4.5 million tonnes of paddy straw. Rice and wheat harvesting results in significant amount of agricultural residue in the field, which is typically burnt directly in the field (in-situ) by farmers which pollutes the environment. In-situ crop residue management refers to crop residue management in the field, and ex-situ crop residue removal refers to crop residue removal from the field. Ex-situ residue management is not economically feasible due to the large volume of paddy residue that must be collected and transported (Modi et al. 2020). Burning of paddy crop residue and emission of GHGs, paddy residue management techniques are shown in Fig.

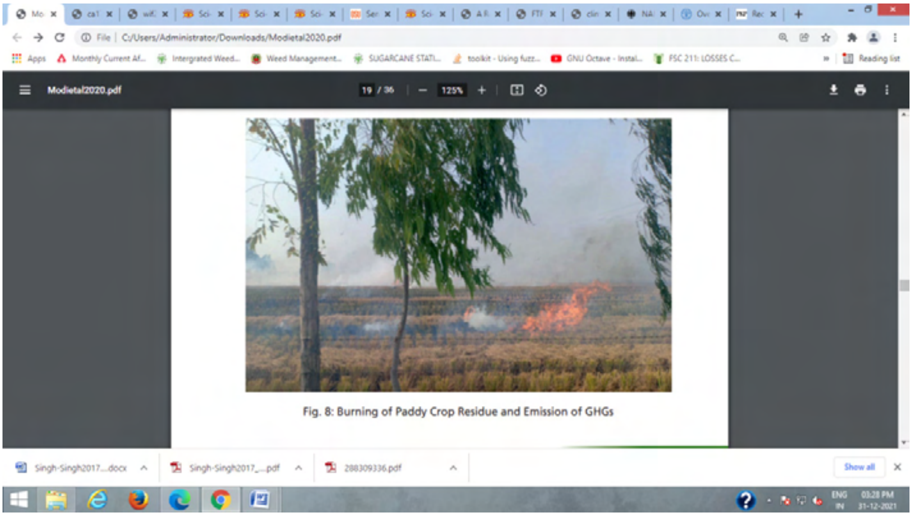

Fig. 8: Burning of Paddy Crop Residue and Emission of GHGs

Figure 14. Crop residue burning in the field (source: Modi et al. 2020)

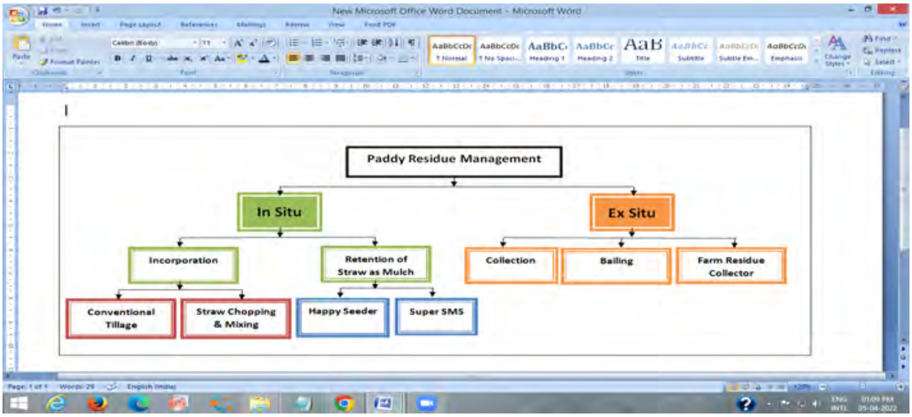

Figure 15. Paddy straw management (source: Modi et. al. 2020)

Mitigation techniques that were effective in reducing the carbon footprint from various agricultural activities included the use of climate smart farm machinery, wheat–rice straw management, efficient use of fossil fuel and other non-renewable energy sources in the agriculture system, improving soil carbon sequestration through straw return, plantation, limiting deforestation, appropriate fertilizer use, crop rotation, irrigation management, bio-char application, and reduced tillage.

10. Optimum machinery management for rice cultivation in eastern India

Level of farm mechanization in rice-based farming systems of eastern India is lesser as compared to western and northern India. It is due to lack of technological intervention and effective extension services at the appropriate level for rice crop development, crop protection, processing, and value addition. It is, however, picking up, and numerous small and large farm machines can now be seen in eastern India. In some places, even combine harvesters are utilized to harvest rice crops. Fragmented land holding and poor economic status of farmers are some of the causes for lower mechanization status of eastern India.

West Bengal has the highest area coverage (84%) and production of rice among all eastern Indian states. Due to fragmented land holding and lower farm power availability, the state has been far behind in mechanization of rice cultivation as compared to Punjab and Haryana. However, in some pockets of the state, there is example of good adoption of farm machinery for rice cultivation. Rotavator has been preferred for primary tillage and puddling in almost all three seasons of rice. Eight row riding type transplanter and cono weeder have been adopted in villages near IIT Kharagpur after successful demonstration. Spraying of insecticide is mostly done using knapsack sprayer. For harvesting and threshing, combine harvesters are now being adopted on custom hiring basis (Tewari et al. 2012). Some similar pattern has also been observed in Odisha. A was conducted by Mohapatra et al. (2017) to analyze the impact of farm mechanization on rice cultivation in Bargarh district of Odisha put some light on it. Shortage of labour and higher cost of it caused adoption of farm machinery in that area. Rotavator, thresher and combine harvesters were the major machines being used for rice cultivation. Although other operations still remain manual.

For improvement of mechanization in rice in eastern India some measures can be taken. Land preparation with rotavator is a better option for combined tillage and puddling of rice field which saves labour and cost both substantially. In transplanted rice, major energy and cost are involved in transplanting operation. Adoption of mechanized transplanting can alleviate this problem. Self-propelled light weight boom sprayers are better option for spraying of pesticide compared to knapsack sprayers. Harvesting with combine harvester and self-propelled vertical conveyer reaper is labour and time saving compared to traditional harvesting and threshing practice. To bring a successful mechanization model, custom hiring centres are necessary as marginal farmers are large in number who cannot afford bigger machinery.

Small two-wheel tractor also called power tiller with rotary tiller attachment is a good machine for puddling operation. The light weight version of it is also suitable for women. Four row walk behind type self-propelled transplanter is light weight and easy to operate. The combination of power tiller and transplanter together can also reduce the cost and fuel as compared to traditional disc ploughing (Biggs et al. 2011; Diao et al. 2012). SRI transplanter and weeder are another example of climate friendly and women friendly machinery package. Battery powered reapers have been developed which are gender neutral as well as environment friendly and can be very well adopted for small land holdings of eastern India.

11. Conclusions

Machines and equipments for mechanized cultivation of rice have been developed and available commercially. Local level problem solving and large scale extension of these machines are necessary for increasing mechanization level in different parts of the country. Determination of optimum conditions in terms of cost and energy is also necessary for convincing the farmers. Custom hiring based machinery banks are required to be established for adoption of large machines by medium and marginal farmers. Rural entrepreneurs can be trained to operate and maintain large machines like combine harvesters for small scale business. These machines can be called to the local sites from more advanced states like Punjab and Haryana on hiring basis. Transplanting takes away the major chunk of cost and energy in rice cultivation. Direct seeding using paddy drum seeder may be promoted by large scaled demonstration. SRI has been found to be a superior rice cultivation technology as far as the climate change is concerned. The major hurdle in this system is transplanting young seedlings. An efficient, light weight SRI transplanter can solve this problem to a great extent. Other than tillage, puddling and harvesting, all operations can be done with battery operated equipments and this need local level innovations and improvements over existing available tools and equipments.

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Links:

- Harvesting and threshing equipments, https://aicrp.icar.gov.in/fim/salient-achievements/harvesting-and-threshing-equipments/
- ICAR-NRRI developed farm implements for rice mechanization, https://icar-nrri.in/agricultural-implements/
- Mechanization and postharvest, https://www.irri.org/mechanization-and-postharvest
- Plant protection equipments, http://www.hillagric.ac.in/edu/coa/agengg/lecture/243/Lecture %2015_Plant%20Protection.pdf
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- Self propelled light weight boom sprayers, https://aicrp.icar.gov.in/fim/wp-content/uploads/2017/01/28.Self-propelled-light-weight-boom-sprayer.pdf
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Chapter 11

Rice based Integrated farming system: A key component of climate resilient rice production systems

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Abstract

Climate change is widely recognized as one of the most imperative issues confronting humanity today. It is a direct threat to our food production system specially under rice production system. Developing agricultural systems that will prove to be resilient to extreme weather events and other related biotic stress like, weeds, diseases and insect pests is essential for ensuring climate-resilience and sustainable food production. However, building a resilient farming system and increasing food production sustainably is a longstanding challenge for smallholder farmers of rice ecologies. Integrated farming system (IFS), that is multidisciplinary and based on a whole-farm approach, is emerging as a nature-based solution in boosting productivity in climate-stressed regions. A whole-farm" approach, that supplement traditional crops like rice with other farming enterprises and a buffer in increasing the production, income and generate employment thereby reducing farming risks in climate uncertainty. IFS promote farmers' knowledge and efficient recycling of on-farm resources and reduce dependence on external inputs. Future research may explore how these farms may be used to achieve 'strong' agricultural sustainability in the vulnerable rice agro-ecosystems

Keywords: Integrated farming system, rice, climate change, vulnerable

1. Introduction

Rice is the most important cereal grain, feeding more than half of the world's population, and is widely adapted to a wide range of climatic zones across continents (temperate, tropical, sub-tropical, and semiarid). Rice is suited to a wide range of habitats, including irrigated lowland, rainfed lowland, and upland locations. 80 million ha of irrigated rice lowlands provide for 75% of total global rice production. The cultivated lowland system accounts for 56% of Asia's total rice area (Swain and Singh 2005). From the standpoint of food security, these irrigated plains are the primary rice producing areas, particularly on the Asian continent. The lowland irrigated areas system accounts for over 20% of worldwide rice production, and these areas, which include South Asia, portions of Southeast Asia, and the African continent, are plagued by a variety of abiotic stressors as well as erratic rainfall. The upland rice system is most popular on drylands without irrigation and in places where puddling is prevalent. It has a land area of roughly 14 million ha and contributes 4% of total global rice output. Ninety-five percent of all rice is grown in underdeveloped nations, with grain yields ranging from less than one tonne per hectare in very poor rainfed regions to more than ten tonnes per hectare in well-irrigated temperate systems, respectively. Rice is farmed in India over 43.67 million hectares throughout diverse agro-ecological zones, with around 40% of the land under rainfed conditions. The eastern zone, namely Assam, Bihar, Chattishgarh, Jharkhand, eastern Uttarpradesh, Madhya Pradesh, Odisha, West Bengal, and the north eastern hill range, are home to these rainfed regions. Rainfed uplands are generally drought prone in these states, whereas rainfed lowlands are flood prone during the rainy season and drought prone during the dry season. More than 80% of rice farmers fall into the small and marginal categories, with less than a hectare of land and farming providing barely a third of their monthly income. Two-thirds of the earning comes from wage labourer from non-agricultural activities or they migrate to the nearby cities in non-farming season as a construction labourer.

2. Vulnerability to climate change and problems in rice-growing regions

In rainfed rice fields, the main issue is an unexpected or sudden rainfall pattern, which leads to a number of abiotic stress occurrences. Drought affects over 27 million hectares of land. Floods wreaked havoc on nearly 20 million hectares, causing deep water to persist for months. Fields are sometimes inundated with a little more than 100 cm of water. Degraded soils have an impact on the produce as well. The problem of salinity affects coastal locations. Poverty is the key factor affecting production dependability in lowland rainfed rice habitats, as farmers cannot afford fertiliser or better seed. Upland rice habitats have a wide range of climates, ranging from humid to sub-humid. The topography spans from flat to strongly sloped, and the soils vary from somewhat fertile to extremely infertile. Additional restrictions include a small population and limited market access. Poverty and the traditional agricultural practice, which includes extended fallow periods, are the factors limiting crop productivity in this upland eco-system. The frequency and intensity of extreme climatic occurrences has grown in recent years and is expected to climb further in the foreseeable future situation (World Bank, 2013). Because of their higher reliance on agriculture, tiny landholdings, and a lack of funding, technology, infrastructure, and institutions to deal with such shocks, Eastern India is especially vulnerable to climate extremes. Climate change causes greater temperatures, more intense rainfall, and a rise in the frequency and severity of extreme weather events such as floods, droughts, and heatwaves (IPCC, 2014). Communities, livelihood, and infrastructure have already been harmed, and the situation is expected to deteriorate in the following years and decades. Temperatures and rainfall have risen in recent years, and annual rainfall distribution is largely variable in India's eastern regions. Rainfall is expected to rise in practically all districts of eastern India in the 2030s, compared to the historical era, during both the wet (June to September) and dry (October to May) seasons.

Obstacles such as diminishing cultivable land, fragmented agricultural areas, tiny land holdings, and environmental issues, exacerbate the situation, especially in emerging countries (Soni et al.,-2014). Flood-prone eastern India especially Bihar, Odisha, and West Bengal will undoubtedly worsen as a result of climate change. Droughts have struck these states in the past. As a result, it's critical to combine flood and drought management measures to guarantee that losses are minimized and successful adaptation occurs. Agriculture crops have precise temperature and water needs that must be met in order for them to grow. Higher temperatures in the eastern states' diverse areas are expected to have a negative influence on agricultural growth and output. When combined with rising rainfall, this could encourage the spread of contagious diseases and pests into new areas. Heavy rain events predicted could harm crops, resulting in crop loss and a negative impact on farm income and livelihoods. As a result of differences in the distribution and intensity of rainfall, temperature warming, and the occurrence of heavy rainfall events, climate change may put additional strain on agricultural systems. Climate change could have an impact on both wildlife habitats, and the entire ecosystem. The anticipated rise in heavy rainfall events may result in an increase in pests and diseases. Higher summer temperatures, on the other hand, may increase the biomass fuel burden in forests, resulting in forest fires. To deal with climate change and its multiplier effects on social and economic inequities, we must strengthen faculties that ensure the use of climate data and information as well as the flow of vital climate data to researchers and policy-makers. This project is an attempt in that direction. Building climate resilience to make anticipation, absorption, accommodation, and recovery capabilities from the effects of a potentially detrimental activities has a number of advantages (CSTEP 2022).

Adaptations options for rice ecologies

Small and marginal farmers can benefit from an integrated farming system, which is a combined method aiming at effective and sustainable operation for higher production based on a whole-farm perspective (Mamun et al., 2011). Many IFS-related improvements have shown to be advantageous in terms of natural resource conservation, resource efficiency, and climate adaption (Srinivasarao et al., 2017). Recycling system that works with an IFS to convert trash into resources on the farm. It entails the spatial and temporal arrangement of various components like as trees, crops, and livestock on the same amount of area in order to maximize the use of available agricultural resources. Plants, animals, mushrooms, aquaculture, and other aqueous plants and animals are all maintained for optimal output while complementing one another. Waste from one constituent is recycled and utilized as a resource for another. It is a technique for preventing the depletion of land and water resources. Monocropping increases dangers in nations like India, where the majority of farmers have less than a hectare of land and practice subsistence farming. Integrated farming offers enormous potential of making farmers climate-aware by allowing them to grow many crops on the same piece of land and using farm resources sustainably:

- For best output, integrated farming entails integrated resource management.
- It entails making the most of available growing area using an integrated farming method.
- The farm family's nutritional and economic stability is assured, resulting in greater health, because they have access to a variety of fruits, grains, vegetables, animal products, and cash crops grown on their own property. It improves food security by encouraging local production and consumption while also limiting migration.
- The physical and chemical features of the soil, as well as its nutritional status and biological components, are all improved as a result. Such interactive systems have an impact on the microclimate and provide a solid foundation for improved agricultural output.

The selection of IFS components is location-specific, since it is influenced by a variety of elements such as agro-ecological conditions, soil type, market facility, customer demand, farm resources, and so on. In a lowland environment like Cuttack, Odisha, Nayak et al. (2018) showed a 50.4 percent increase in soil accessible nitrogen, 66.6 percent increase in soil available phosphorus, and 150 percent increase in soil available potassium in rice-fish-duck IFS, over the traditional rice cultivation. The addition of fecal debris, as well as the scooping and churning of soil by fish and ducks in the rice field, caused these impacts. In comparison to conventional rice farming, the IFS produced 2.88 times greater rice equivalent output and 58.4 percent higher gross benefit: cost. Several studies have shown that IFS is more sustainable, with better crop equivalent yields, net returns and offers more employment opportunities to families associated with farming (Paramesh et al., 2019). To disperse risks among crops, farmers choose to combine crops with low-correlated returns. If a crop fails to perform well when exposed to danger, the loss might be partially offset by gains in a crop that is more resistant to risk.

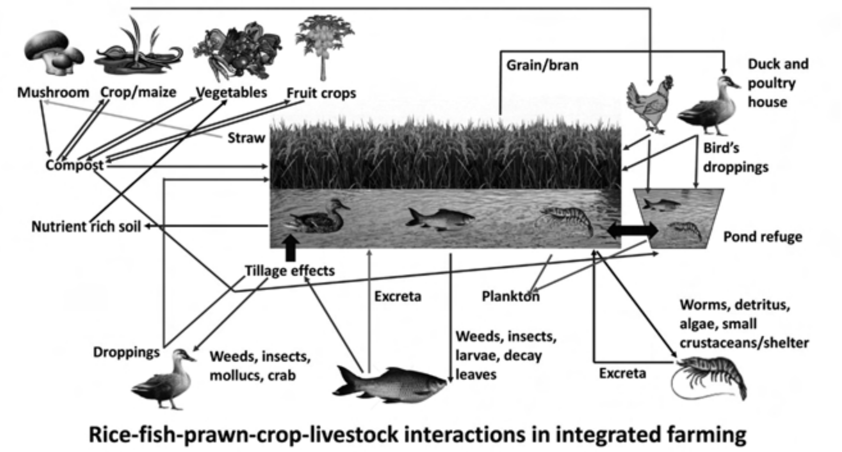

Figure 1. Rice, fish, prawn, crops, livestock interactions in integrated farming

3. Rainfed upland Farming System

For rainfed uplands where both productivity and cropping intensity are low due to erratic rainfall and the farmers are resource poor, the characters like moisture stress (deficit/excess) tolerance; higher inputs use efficiency; suitable duration to accommodate next crop and better compatibility need to be incorporated into the rice varieties for higher productivity. Drought-tolerant perennial timber trees may be grown using rainwater as a supply of valuable fuel wood or timber after a few years. Drought-tolerant, permanent horticulture fruit crops also can be grown to help rainfed farms earn more money. Rainfed soils are thirsty and hungry at the same time. Other operations, such as goats, cattle, poultry, pigeons, and rabbits, will be linked together to supply a large percentage of organic natural nutrients to the soil, resulting in a significant increase in output.

4. Integrated farming system for rainfed lowlands

Over the last 150 years, rice–fish cultivation has been documented throughout tropical and subtropical Asia. Food production and revenue, along with farm integration, gain directly from the conversion of wetlands and paddy fields to rice–fish agriculture (Lightfoot et al., 1992). Among the different rice-based farming systems options, rice-farming bears great promise in the rice ecologies specially the waterlogged and rainfed medium deep and deep water (30-100 cm water depth) situations. Out of the total 43.5 m area, canal-fed irrigated rice is grown in about 16.5 m ha while rainfed rice occupies about 17 m ha under the shallow, medium-deep and deep water ecologies. Eastern India, in particular, with around 5.6 million ha irrigated area and 14.6 million ha rainfed lowlands of the entire 26.58 million ha rice area, has a good prospect for rice-fish farming methods, especially in light of the people's resources, eating preferences, and socioeconomic demands. Rice-fish farming systems with increased land and water resources productivity and job possibilities can assure food, nutrition, and livelihood security for agricultural communities, particularly the most vulnerable populations of small - scale farmers.

*Rice-fish seed farming***.** The rice-fish seed (fry to fingerlings) system is feasible in irrigated, shallow favourable lowlands and waterlogged rice fields. The entire yield of the system is around 8-12 t ha^{-1} of rice (two crops) and 100-300 kg fish (carp) fingerlings each season in the irrigated ecosystem with in-field refuge (trench). In favourable rainfed lowlands, 40 t ha^{-1} ha of wet season rice and 100-190 kg of fish seed can be harvested every season (3 months). The net advantage in fish seed per raising is around Rs. 2000-5000 ha^{-1} per season (Sinhababu et al., 1998).

Figure 2. Rice –fish-livestock based integrated farming system model for rainfed lowland at NRRI

Rice-fish -duck farming. Duck farming in rice fields is practiced in some Asian countries like Indonesia, South Korea and Vietnam. In India, duck farmers of west Bengal, and Kerala allow the bird to eat in rice fields. Seven day old ducklings can be released at 200-300 h^{-1} in the rice field after 20 days of planting till flowering of the crop. After the rice harvest, ducks may be allowed again to forage in the field. The rice-duck integrated farming could enhance effective tiller number of rice, depress ineffective tiller process while increasing rice panicle number and its percentage and seed setting rate. All these traits would help improve rice yield. These positive effects would possibly be related to duck activities such as foraging, muddying, trampling, striking, and physical stimulation (Poonam et al., 2021).

Rice- prawn seed farming. Fresh water prawn (scampi, *Macrobrachium rosenbergii*) seed (post larvae to juveniles) rearing can be taken up with rice in favourable lowlands realizing around 3.0 t ha^{-1} of rice and 83 kg ha^{-1} of prawn seed within 100 days during wet season (Sinhababu et al., 1998).

Rice-grow-out fish farming. The rice-grow-out fish culture can be practiced in irrigated, rainfed medium-deep and deep water rice ecologies. Different compatible crops, birds, livestock and other enterprises can be integrated in this production system.

Rice-fish-horticultural crops farming. Integration of vegetables and fruit crop on bunds of rice- fish system can further increase the productivity and net farm income to the tune lf Rs.22,450 ha^{-1} (Rautaray et al., 2005). Sewage fed rice-fish-horticultural crops system has the production potential of 9.3-10.8 t ha^{-1} rice (two crops), 0.5-1.2 t ha^{-1} fish and 90-107 t ha^{-1} horticultural crops yr^{-1} (Rao *et al.,* 2014).

Rice-fish-Azolla farming. Integration of allied components like, Azolla and fish with rice in irrigated and lowland ecologies is feasible and it can provide scope for bio-resources recycling. The quantum of organic residue and N added through recycling was higher in rice-rice+Azolla+fish farming with the incorporation of green manure. The unutilized fish feed, decayed Azolla and fish excreta settled at the bottom of fish trench had a higher nutrient value, which can be recycled to enrich the soil.

Rice-ornamental fish farming. The National Rice Research Institute (NRRI), Cuttack developed a technique for breeding and culture of ornamental fishes in waterlogged rice fields during the wet season, followed by growing dry season irrigated rice crop with ornamental fish, yielding 25,000-6,00,000 ha^{-1} of ornamental fish as well as almost 3.5 and 5.0 t ha-1 of rice grain during the wet and dry seasons, respectively. Women farmers, as well as Self-Help Groups, can engage in this farming.

Rice-fish sequential/rotational system: This system is practiced in the deep-water areas and in coastal wetlands/flood plains. In deep water areas, fish (carp) culture is done during wet season, followed by growing a high yielding rice crop during dry season with a productivity of 5-6 t ha^{-1} of rice and 1000-1250 kg ha^{-1} of fish yr^{-1}. Horticultural crops and duckery are integrated on dykes. In the coastal saline areas, salt tolerant rice, fresh water fish and prawn mixed farming is done in the wet season, followed by brackish water-fed prawn and fish culture in sequence during the fry season. This type of farming requires proper design and field construction and adoption of management packages for rice as well as freshwater and brackish water fish and prawn. This system can produce around 2.7t ha^{-1} of rice grain and 0.8 t ha^{-1} of fish and prawn yr^{-1}.

Case Study

Coastal region of Odisha's Jagatsinghpur district has been hit by cyclonic storms and floods regularly for more than two decades. This has been severely affected the livelihood of the communities living in the area. The district is mostly mono-cropped in flooded lowlands during wet season followed by green gram or fallow mostly due to salinity or drought in the lack of irrigation water. This is also associated with low productivity, increased cost on agricultural inputs and poor or non-utilization of existing agricultural resources available in the farm. The traditional farming also created ecological problems on crop diversity, livestock and poultry, as well as soil and water pollution. Shri Akshay Kumar Nayak, a dedicated and innovative farmer, hails from village Mohammadabad in Tirtol Block of Jagatsinghpur District have land holding of 3.0 acres of homestead land and 3.5 acres of shallow to deep land where 40 to 50 cm of water is stored during the rainy season and only rice can be grown in these fields. He realized that doing agriculture by traditional method failed to provide profitable yield and income in the risk prone coastal Odisha. In search of a new method he came across IFS models of National Rice Research Institute, Cuttack while exposure visit under RKVY funding. At NRRI he learnt about improved rice climate resilient varieties like CR Dhan 801, Pradhan Dhan and Maudamani which yielded >8.0 t/ha for his shallow lowlands, Further he gained knowledge on management of residue recycling within the farm and developed a mushroom unit and avermi-composting unit with the capacity of 2.0 tonnes. Diversification of his farm through improved climate resilient varieties, better fisheries, horticultural crops, duck rearing and mushroom reduced his risk to climate change and provides him with the net annual income of Rs 6,89,000/annum apart from this, the production of 2 tonnes of vermi-compost by residue recycling from mushroom unit helps him to save Rs 2,71,000/- Impressed by his success many nearby farmers of Jagatsinghpur district have started converting their land into rice-based integrated farming system. The farmers face problems during the implementation of IFS in rice agro-ecologies are:

- Non- availability of quality inputs like paddy seeds, fish fingerlings, ducklings/ chicks, fruit saplings in the state department as well as local area.
- Lack of knowledge about the management of integrated farming system specially residue management towards reducing the cost of cultivation and preventing environmental degradation.
- Lack of marketing facilities in the local area and delay in sale of perishable produces, forces the farmers to sell them to the middleman at throw away prices.
- Due to the volatility in the market price, farmers has to face unstable income of their produce.
- Irregular or excess rainfall due to climate change makes it impossible to sow/ harvest the vegetable crops and other enterprises on time.

Figure 3: Integrated farming system of farmer at Jagatsinghpur distrct of Odisha

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Chapter 12

Organic Rice Cultivation: Eastern Indian Perspective

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Abstract

India is the home of highest number of organic producers in the world. Resource-poor marginal farmers are many a times found to be 'organic by default' while people of eastern India meets most of their calorie demand through rice. higher profit from organic produce due to premium price and additional environmental benefits during the cultivation showed an encouragement towards adoption of organic farming. Minimizing the dependence of synthetic inputs (agrochemicals) in organic farming leads to improve environmental quality by enriching soil C pool, soil physical structure, reducing nutrient leaching and promoting soil biodiversity. This also protects and modernizes the indigenous knowledge in agriculture. Although, worldwide research on organic agriculture indicates dichotomy of its effects towards mitigation of climate change; but better management of organic farming may perform positively. Yield stabilization through organic management in rice is often highlighted. Organically produced rice especially aromatic rice in eastern India has a tremendous future in domestic as well as international market. However, wide scale adoption of organic farming still needs a wholesome planning both at farmer level and policy level which also demands a sound knowledge regarding organic standards and certification.

Keywords: Low-input agriculture, soil health, environmental pollution, yield sustainability, organic produces

1. Introduction

Organic agriculture has always been a complex phenomenon in all aspects of discussion from very beginning after its reintroduction as a corrective measure against the ill effects of input intensive farming practices. Today's challenge is making entry of the organic products and commodities into the policy of different countries as well as into global market. During the last 20 to 30 years, a significant positive momentum has been seen in the global level towards sustainable environmental development and food quality. The pace of transformation of organic farming practice demanded by modern world is not same for India, although, 'Organic Farming' is very much native to India. However, across the countries or region the concept of organic farming is generally remains almost similar and based on 'Nature' being the role model for farming, as it does not use any synthetic chemical inputs and the whole system is based on natural ways of life. The organic system of cultivation does not focus onto over exploitation of the soil and avoids its degradation. Organic farming emphasizes the protection and nurturing of living soil microbial population and other organisms which are significant contributors to its fertility on a sustained basis. As per FAO's definition "Organic agriculture is a unique production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles and soil biological activity, and this is accomplished by using on-farm agronomic, biological and mechanical methods in exclusion of all synthetic off-farm inputs".

The agricultural area under organic cultivation has increased about four times from 11 m ha in 1999 to about 43.7 m ha (including in-conversion areas) in 2014 (Lernoud and Willer, 2016); which depicts the growing popularity of organic agriculture. During 2015-16, about 1.35 million metric tonnes of certified organic products including sugarcane, cereals, millets, cotton, oil seeds, pulses, vegetables, medicinal plants, tea, fruits, spices, dry fruits, coffee were produced. In India, about two third farmers are small and marginal. However, India had highest number of organic producers globally in 2020 (about 1.60 million), with about 2.66 m ha (which is 1.48% of its total agricultural land) is under organic agriculture (Willer et al. 2022). During same time, total area under organic certification in the country was 4.34 m ha including 2.66 m ha agricultural area and rest 1.68 m ha was under forest and wild collection of minor forest produces (Willer et al. 2022).

Intensive agricultural system causes degradation of soil due to imbalanced use of chemical fertilizers, very limited addition of crop residues and manure (Rahman and Barmon 2019). At present, large number of farmers involved in alternative farming practices in the states of eastern India. Main insight behind this is, a huge number of "Organic by default" farms are there which have either never been managed with chemical means or have converted back to organic farming because of the farmers' beliefs or purely for economical reason. Their precious resource i.e., land, need to be prevented from degradations through the organic farming system approach. So, the available farm area must be optimally used to its fullest potential to produce a range of nutritious and healthy food as well as other required commodities to feed a small family and simultaneously maintain soil health and productivity.

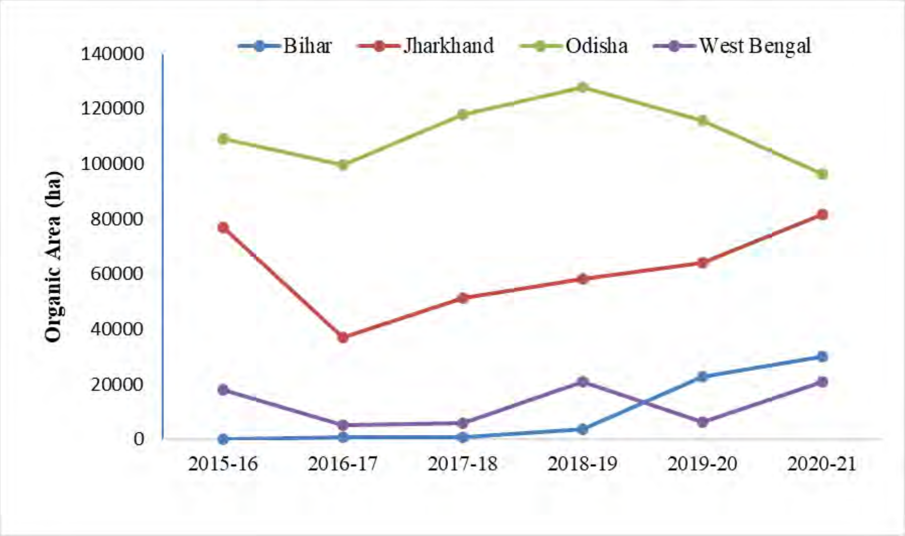

Figure 1. Area under organic certification process in eastern states of India during 2015-2021 (cultivated + wild harvest) (Source: APEDA)

In eastern India, states like Odisha and Jharkhand have greater reasons for adoption of organic farming due to less use of fertilizers and pesticides in general and most of the farm holdings are small and marginal (Fig. 1). And majority of the farmers are resource poor. On the other way, organic agriculture is a potential sector for efficient utilization of different organic matters viz. agricultural waste, forest debris, animal waste, rural and urban residues. In West Bengal, organic tea and short grain aromatic rice *viz.* 'Gobindabhog', 'Tulaipanji' are of high demand and being exported to foreign countries. Organically produced grains, pulses, vegetables and fruits are increasing their presence in the market. Moreover, large area in this part of the country is rainfed which impose restriction towards high input intensive agriculture. Moreover, organic farming may serve complementarily in the era of conservation agriculture for sustainable farming.

2. Components and management of organic farming

The success of the organic farming system depends on the efficient use of organic manure and other crop wastes, symbiotic nitrogen fixation with legumes, suitable crop rotation, effective biological pest control, and effective integration of crop and animal husbandry in the system. Organic farming emphasizes on the liveliness of the soil. A live, healthy soil with proper crop residue management and effective crop rotation can sustain optimum farm productivity in long run, without any loss in soil productivity. Organic farming is distinguished from conventional modern farming in the way it is managed and the inputs it uses. Soil is maintained by continuous incorporation of crop and weed biomass, manures (FYM, vermicompost), biofertilizers and bio-stimulants, special liquid formulations (like vermiwash, compost tea, etc.) during the cropping cycle.

2.1 Crop rotation

Crop rotation is essential to maintain soil health and to allow the natural microbial systems working, and considered as the back bone of organic farming. High nutrient requiring crops like cereals and vegetables should precede and follow a legume crop. Rotation of pest-host and non-pest-host crops help in controlling the soil borne diseases and pest which is done by following a 3-4 years of crop rotation cycle. The benefits of crop rotation are multidimensional *viz.* controlling weeds, improving soil structure through different types of root system. Green manure crops like sesbania should find place in planning the rotation.

2.2 Green manure

Green manuring is an important component of integrated nutrient management and the cheapest and safest way to supply nutrients to the cereal crops where supply of other organic compost is inadequate. Before the era of synthetic fertilizers, green manuring was invariably practiced in rice, wheat, etc. Green manuring comprises the ploughing or intermittently adding of un-decomposed green plant material (leaf, tender stem) into the soil to improve the soil physico-chemical quality and fertility (Mahajan et al., 2002). For green manuring, leguminous crops are preferred because of the capacity of fixing atmospheric nitrogen (N) (Gupta et al., 2005). Green manuring mobilizes nutrient from added residues in addition to chemical fertilizer, thereby it also reduces release of greenhouse gases (GHGs). Green manuring of *Sesbania* in direct-seeded rice can substitute about 40 kg N ha^{-1} under flood-prone lowland conditions (Sharma and Ghosh, 2000). Application of N-fixing tree biomass (leaves and twigs) improved the rice yield and farm income as well as maintained the soil health (Das et al. 2010). The crops mainly used for green manuring are: *Sesbania aculeata*, *S. rostrata*, *Crotolaria juncea*, *Phaseolus vulgaris*, *Vigna unguiculata, Vigna radiata*, *Cyanopsis tetragonoloba*, *Trifolium alexandrinum*, *Meliolotus alba* and other short-duration legume crops.

2.3 Organic Manures

Farm yard manure and other organic manures supply most of the macronutrients and micronutrients. It improves soil physico-chemical properties such as aggregation, aeration, permeability, increase in cation exchange capacity which helps in water holding capacity and promote slow release of nutrients, and health of soil by stimulation of soil flora and fauna. Organically grown rice using poultry manure alone or along with liquid manure (poultry manure 100% RDN + top dressing with liquid manure at 25 and 50 days after transplanting (DAT)) was found to be the most promising not only for higher growth and productivity but also for higher profit (Nayak et al. 2021).

2.4 Biofertilizers

Biofertilizers are ready to use live formulates of beneficial microorganisms which improves the availability of nutrients by their biological activity when applied to seed, root or soil and help in increasing the population of micro flora (Rajendra et al. 1998). Use of biofertilizer is considered as a sustainable way to improve soil quality in modern agriculture and an essential component of organic farming. The mutualism of non-legume crops and N-fixing bacteria is of great importance with strains of *Azotobacter, Azospirillum*, *Acetobacter*, *Bacillus*, *Pseudomonas*, *Rhizobium and Bradyrhizobium* which are used as biofertiliser in different cropping systems. In organic rice production system Azolla, blue green algae (BGA), Rhizobium, Azotobacter, Azospirillum, Acetobacter and phosphate solubilizing microorganisms are widely used.

Improvement in soil organic carbon, as well as soil chemical and biological characteristics in acidic sandy loam soils of the N-E region of India was observed with application of enriched bio-compost and biofertilizer on in rice (Buragohain et al. 2018). Further, application of enriched bio-compost @ 2 t ha^{-1} which substituted 2/3rd of recommended inorganic N and phosphorus (P) fertilizers in rice resulted in significant improvements in soil nutrient status, microbial populations, enzyme activities and grain yield. Microorganisms are the major players to produce important bioinoculants in agriculture including rice. Yield improvement due to the application of biofertilizers might not be solely due to N fixation or P solubilization, but also because of many other factors such as release of growth promoting biochemical compounds, chelates, control of plant pathogens, promoting growth of beneficial organisms in the rhizosphere.

2.5 Blue Green Algae (BGA)

These are the Cyanobacteria or photosynthetic prokaryotes that are also considered as prominent diazotrophs in wetland rice. Potential nitrogen-fixing BGA species in the rice fields of India are: *Aulosira, Anabaena, Nostoc, Anabaenopsis, Calothrix, Camptylonema, Cylindrospermum, Fischerella, Hapalosiphon, Microchaete, Westiella, Westiellopsis* and *Tolypothrix*. Nitrogen fixed by these organisms is made available to the rice plants through exudation or autolysis and microbial decomposition. These are phototrophic in nature and produce auxin and gibberllic acid, fix 25-30 kg N ha^{-1} in submerged rice fields as they are abundant in paddy, so also referred as “paddy organisms”. Biologically fixed N by associated organisms and Soil N are major sources of N in lowland rice. Nitrogen fixed by free living and rice plant associated bacteria can met about 30% of N demand of rice. BGA forms symbiotic association with fungi, ferns and flowering plants and fix N, but the most common symbiotic association has been found between a free-floating aquatic fern, Azolla and *Anabaena azollae* (BGA).

2.6 Azolla

The practice of Azolla is an age-old technique popularized as ‘green’ nitrogen fertilizer to increase rice production. Azolla contains 2-5% N, 0.3-6.0% K on dry weight basis and considered as a good source of organic manure and nitrogen for rice crop. Azolla decompose within a short time in the soil and increase N availability to rice plants. Average N-fixation through azolla is estimated at 30-40 kg N ha^{-1}. Less than 5% of the nitrogen sequestered by azolla is available immediately to the growing rice plants, while rest 95% remains in the azolla's biomass until the plant dies.

2.7 Vermicompost

Vermicompost serves as an effective organic nutrient source that enhances physico-chemical properties and microbial activities of soil (Lim et al. 2014). During evaluation of black rice varieties under organic nutrient management, it was found that, application of vermicompost along with microorganism solution resulted in the highest number of panicles per hill and grains per panicle, however, lowest number of panicles per hill and grains per panicle was observes with application of 'Jeevamrutha' (Behera et al. 2021). Following organic nutrient management in rice including FYM and vermicompost along with *Azospirillum*, P solubilizer and neem cake can produce profit of about 40000 (INR) from one hectare of land (Nayak et al. 2017).

2.8 Weed management

Weeds are considered as the second most yield restricting factor after nitrogen-availability and are major menace in herbicide-restricted organic agricultural systems (Hokazono and Hayashi 2012). For efficient weed management, cultural techniques comprising of direct mechanical and thermal methods in combination (Lampkin 1994; Stockdale et al. 2001) may be beneficial. Proper crop rotation, timely water management and precision land levelling are among the potential strategies. Mechanical weeding using different weeders viz. star weeder and cono weeder are also used for controlling weeds in rice.

2.9 Pest and disease management

Generally, plant protection measures are considered only in the case of problematic situation in organically managed crop. Successful management of organic crops must exclude the use of synthetic chemicals thus the insect pests and disease are managed through either agronomic (cultural and mechanical, biological or by botanical extracts) practices. In some cases, use of some chemicals such as copper sulphate and soft soap are also accepted. However, use of disease-free seed materials and resistant varieties is always recommended. Biodiversity maintenance, crop rotation, ecological engineering and use of trap/catch crops are effective practices which can keep the population of pests below economical threshold limit (ETL). Mechanical removal of disease affected plants and/or plant parts, collection and destruction of egg masses and larvae, installation of pheromone traps, light traps, sticky trap, and bird perches are most effective mechanical methods of pest management. Use of predators and pathogens has also proved to be effective method of keeping pest problem below ETL.

Plant protection measures varied region wise according to the availability of different indigenous plant and other materials. Few popular innovative seed treating formulations are Panchgavya extract, beejamrut, Dashparni extract, hot water treatment, cow urine or cow urine-termite mound soil paste, asphoetida water, turmeric rhizome powder mixed with cow urine. However, with increasing scientific interventions into organic agriculture use of bioinoculants e.g. *Trichoderma viride* or *Pseudomonas fluorscens* and biofertilizers (Rhizobium, Azotobacter, PSB etc.) are becoming more pronounce.

Biopesticides are biochemical pesticides that are naturally occurring substances that control pests by nontoxic mechanisms. Biopesticides may be living organisms (natural enemies) or their products (phytochemicals, microbial products) or byproducts which can be used for the management of pests that are non-toxic to plants. Biopesticides provide great opportunity in managing crop pests, however, these are most commonly used in combination with other plant protection tools as part of Biointensive integrated Pest Management approach. Biopesticides are considered eco-friendly and safe to the humans because they are targeted to specifically a single pathogenic pest. These include bio-fungicides (Trichoderma), bioherbicides (*Phytopthora*) and bioinsecticides (*Bacillus thuringiensis*). There are viral biopesticides such as granulosis viruses and nuclear polyhedrosis viruses. Spraying nuclear polyhedrosis viruses of *Helicoverpa armigera* or *Spodoptera litura* (S) @ 250 larval equivalents are found very effective. Use of plant based biopesticides like 'Neem azal 1%' and Karanja oil (2%) and microbials like 'Dipel WP' and 'Myco-Jaal 10% SC' was found to be encouraging in controlling lepidopteran as well as sucking insects and enhancing yield of rice (Sharma and Aggarwal 2014). Compared to common synthetic insecticides, these eco-friendly formulations may support to raise a successful organic rice crop and provide the farmers with better alternative.

Use of green manuring, vermicompost, azolla and rock phosphate amended with *P. fluorescence* can effectively manage the sheath rot disease in organic rice cultivation without hampering the yield as well as improving population of soil rhizospheric microbes (Das et al. 2020). 'Brahmastra' is a mixture containing different type of plant leaf extracts used in management of insect pests due to presence of few alkaloid compounds in extract having biopesticidal feature to control the sucking insects. Srinivasarao et al. (2020) found least number of leaf folder hill^{-1} with seed treatment and foliar spray of 'Brahmastra' which produce similar results with seed treatment and foliar spray with "Brahmastra' coupled with soil application of *Trichoderma harzianum* @ 130 kg ha^{-1}.

Many organic farmers and NGOs have developed large number of innovative formulations such as Diluted Cow urine (for pathogens and insects), fermented curd water (management of white fly, jassids, aphids), 'Dashparni' extract (fermented mixed extract of neem papaya, custard apple, pongamia, castor, nerium leaves with green chilli, garlic paste, cow dung and cow urine), neem-cow urine extract (for sucking pests and mealy bugs), chilli-garlic extract (against leaf roller, stem/ fruit/pod borer) which are effectively used for control of various pests.

3. How organic farming is beneficial for soil and environment?

Organic farming is one of the several approaches found to meet the objectives of maintaining soil quality and sustainable agriculture. Organic farming improves soil health and preserves biodiversity. Organic farming also has the potential to mitigate climate change by decreasing the emission of GHGs emissions and enhancing soil carbon sequestration in the system. Energy use is also considerably less (about 50% less) under organic than conventional management.

Application of organic manures and compost enriches the soil organic carbon (SOC) pools and achieves long-term soil C-sequestration. Compared to application of same amount of chemical fertilizers, organic manure increased the organic carbon contents in soils along with the advantages of improvement of soil productivity and mitigation of CO_2 emission from (Pathak, 2015). Lenka et al. (2017) observed that the GWP per unit grain yield was lowest under organic nutrient management (ONM) over rest of nutrient management (INM and NPK) of soybean-wheat rotation in Vertisols of central India.

In other study revealed that a ccombined treatment of organic farming and reduced tillage techniques could favour both C-storage in soil (as high as 500 kg C ha^{-1} yr^{-1}) vis-à-vis reduced GHGs emissions (potentially mitigate 65% GHGs emissions i.e., 4.0 Gt CO_2-eq. yr^{-1} (Lal, 2004). A global meta-analysis study unveiled that N_2O emission from non-organically managed soils is driven by total N inputs, but for organically managed soils the same is regulated by soil characteristics (Skinner et al. 2014). 'Inhana Rational Farming (IRF)' technology, an organic way of farming blending both ancient modern scientific knowledge, in order to develop large scale organic agriculture to form 'Sustainable Models' for rice cultivation, based on resource availability. This practice showed that good quality compost increased the soil quality, especially for soil biological properties (Rahman et al. 2020).

4. Organically managed rice cultivation: Eastern Indian scenario

Rice has been a predominant crop in lower Indo-Gangetic plain (IGP) belongs to Eastern India covering the states like Bihar, West Bengal, Odisha, Jharkhand. Despite intra-regional variations in many agricultural parameters like arable area, crops and cropping systems, soil properties, groundwater utilization and irrigation methods, majority of the area remains as moderate to highly productive. However, various reports of post-green revolution era disclosed that excess use of chemical fertilizers might have impacted the soil quality vis-à-vis yield stagnation in the longer run; there comes the relevance of organic cultivation which is more sustainable in terms of yield and natural resources as per various scientific reports.

In an experiment in Bhagalpur (Bihar) showed that organic management practices had sustained both soil health and crop yield over a longer period of time. Among the organic treatments the maximum grain yield (27.39 q ha^{-1}) was found in treatment (75 % N (FYM) basal + 25 % N (vermicompost) at 25

DAT + azospirillum @ 5 kg ha^{-1} + PSB @ 5 kg ha^{-1} + KSB @ 5 kg ha^{-1}). This study concluded that aromatic rice variety *Bhagalpur Katarni*, which have lower nutrient requirement, can be grown with complete organic nutrient management (Sah et al. 2018). In Nadia (West Bengal), Banerjee et al (2013) recommended that combined use of FYM (50% RDN as basal) + mustard cake (50% RDN at 21 DAT) in aromatic rice 'Gobindabhog' equivalent to 50 Kg N ha^{-1} recorded highest grain yield (2.68 t ha^{-1}) and also benefitted residual soil nutritional status, net return and benefit: cost ratio. Bhaduri et al (2020) reported that SOC, TOC contents and availability of major and micronutrients were improved in organic treatments like FYM+Azolla, FYM+Green manure, FYM+Vermicompost in rice based system at NRRI, Cuttack (Odisha). Further, the same treatments could also improve soil microbial activities like dehydrogenase, urease, acid and alkaline phosphatases, β-glucosidase, aryl sulfatase and fluorescein diacetate hydrolysis enzymes.

Highest economic efficiency in terms of B:C ratio (1.73) was observed in (50% FYM (basal) + 25% vermicompost (basal) + 25% vermicompost as topdressing at 10 DAT). This indicated that 50% substitution of FYM with vermicompost and split application of the latter has tremendous effect on the economics of organic rice production (Barik et al. 2011). Singh (2011) at ICAR- Research Complex for Eastern Region (Patna) noticed that vermicompost and (Azotobacter + FYM) both recorded highest rice equivalent yield in aromatic rice-tomato-bottle gourd cropping system. Continuous application of all the organic sources for three years' also recorded SOC buildup in the treatments vermicompost (0.60%), closely followed by Azotobacter + FYM (0.59%) and only FYM (0.58%).

5. Yield challenges and other debates in organic way of cultivation

Although organic cultivation offers some health and environmental benefits, its low-yield potential with respect to conventional farming, often raises the concern among scientists and farming community. Further insufficiency of organic inputs also hampers the crop nutrient requirements. There are diverse opinions about the relevance of organic farming in Indian context. Many experts perceived that despite having some merits in organic farming, practicing organic farming should not be the single option. Rather this can be adopted considering the crops chosen (preferably value-added crops), farmers' risk bearing capacity, and meeting the local and national needs. Experts agree that conventional farming may create environmental pollution but compromising the yield in organic cultivation (more during the initial period) is not a safer option either, with a concomitant increase in the cost of labour to manage the field organically. Other school of thought believes that adoption of organic farming is the only option to conserve tomorrow's ecology than today's benefits (Narayanan, 2005). All these facets of thoughts lead to organic cultivation in a confusing state and remain indecisive regarding the prospect as a globally acceptable alternative agriculture system.

Even there are still some conflicting views on how far organic agriculture can mitigate challenges pertaining environmental and resource issues; although it has been discussed in the scientific fraternity for many years, and if its promotion is an appropriate policy approach to solve socioecological concerns but no clear perspective has been established (Debuschewitz and Sanders, 2022). Bai et al. (2018) reviewed a number of literatures on organic farming and observed a median values of 'organic yield gap' at 11%, though this was not universal, while some reported no significant variation in yield or even higher under organic cultivation as compared to conventional agriculture. In the Nalanda district of Bihar, the organic package of practices proved quite successful for potato yield and quality of supplemented with organic treatments (FYM, vermicompost and poultry manure) over the conventional fertilizer application (Ojha and Saha, 2014).

Although the 'organic yield gap' is reported from various parts of the world, it is also understood that judicious land management like crop diversification (multi-cropping and crop rotations) practices could effectively reduce the yield gap under pure organic systems (Ponisio et al. 2014). Similarly, few other reports also showed a lower long-term yield variability under organic mangement (Smolik et al. 1995; Lotter et al. 2003).

Even some reports contradicted the climate change mitigation potential through organic rice production and reported higher seasonal CH_4 and N_2O emissions under various water regimes as compared to conventional rice paddies in southeast, China (Qin et al. 2010). However, co-benefits of organic agriculture for mitigating agricultural GHGs emissions is often realized in terms of enhanced soil carbon sequestration and reduced nitrogen losses to the environment and together may cut down agricultural greenhouse-gas emissions between 60 and 92% (CH_4 and N_2O) (Niggli et al. 2009; Scialabba and Müller-Lindenlauf, 2010).

Through the course of time different forms and modifications of organic farming has emerged. Comparative studies also conducted by Koner and Laha (2021) to examine the economic viability of two alternative models of organic farming viz. recommended package of organic farming of Burdwan and zero budget natural farming (ZBNF) model in Purulia. For this purpose, the study evaluates the performance of both of these models in terms of three important parameters i.e., cost of cultivation, yield and income. Evidence suggests that organic farmers under both models have experienced a reduction in production costs compared to their non-organic counterparts. However, evidence indicate that organic farmers under both models have suffered a loss in yield because of their decision to convert into organic farming, whereas the non-organic farmers in the same regions have experienced an increase in yield for their crops in the same period. Therefore, empirical evidence raises serious doubt on the ability of both of these models of organic farming in achieving higher yield for the cultivated crops. However, empirical evidence strongly suggests that the ZBNF model of organic farming can play an important role in the income generation of the farmers in Purulia vis-à-vis non-ZBNF model in Burdwan (Koner and Laha, 2021). Despite promotional effort from government and other NGO agencies, subsidies and other schemes, area under fully organic farming is not increased over the years. This is still less than 2% of total arable land in India.

From various literatures, it can be summarized as, apart from loss in crop yield, some other factors remained crucial for adoption of organic farming in large scale, like non-fulfilment of expected quality of organic produce, failure of organic pest management, lack of quality seeds supporting organic farming, shortage of biomass and livestock of waste/bio- resource for compost production, lack of storage, transport and organized marketing system of organic produces, lack of mass awareness and absence of supportive policy interventions, cost involved in organic certification system etc. (Garibay and Jyoti, 2013; Savage, 2016; Hazra et al. 2016; Bai et al. 2018).

Thus, most of the research outcome suggests that, for sustainable rice production will require a rational use of chemical fertilizers with increase in integrated use of organic sources, and utilization of the genetic potential of rice cultivars to make efficient use of nutrients under the constrains of global climate change.

6. Relevance of organic farming in modern agriculture

The growing concern for the intensive chemical-based agriculture has led the way to adopt organic farming worldwide. Large-scale adoption of organic cultivation would help to minimize the issues raised by input intensive conventional farming. To harness the global rice market, both the area under organic rice and productivity should reach to an expected level (Prasad, 2005; Lynggaard, 2006; Wheeler, 2008).

Number of research papers, reviews and meta-analyses suitably evidenced and supported in favour of using organic fertilizer; and considered organic farming systems as more sustainable and environmental-friendly than conventional farming systems (Reganold and Wachter, 2016), with some prominent benefits as follows:

- Organic systems consistently have better soil carbon and moisture levels, hence sustained good soil quality (especially physical and biological soil quality indicators) with less chances of soil erosion over the conventional systems.
- Organic farms usually maintain more plant and faunal diversity (insects, soil micro and macrofauna) and altogether have a better diversified system. As revealed most functional groups (herbivores, pollinators, predators, and producers i.e., plants), are rich and diverse in organic cultivation
- With respect to N and P leaching and GHGs emissions, organic farming systems stand better in point of reduced environmental pollution than conventional farming. Reports said that organic farms were found to have lower NO_3^- leaching, N_2O emissions and NH_3 emissions per unit of field area

- As organic agriculture devoid of synthetic fertilizers, pollution risk of ground and surface waters remains low to minimum risk. Degradation of water quality in river and marine ecosystems is related to eutrophication i.e., caused by excessive use of N and P fertilizers, production of hypoxic zones and thus becoming threats to aquatic lives.
- Organic systems are less energy consuming and more energy efficient than their conventional agriculture. Germany, Italy, Sweden and Switzerland and other European countries partially relied on organic farming for becoming less energy intensive on a per-hectare basis.

7. Social and economic advantages of organic farming

Increased use of chemical fertilizers does not always warrant in sustainable growth of agriculture sector, particularly in respect of production and yield. Analyzing twenty years' data, one study showed that greater use of chemical fertilizers year after, could not achieve greater agricultural production and yield in Hooghly district of West Bengal (Patra et al. 2016). As per their study promotion of organic farming by formation of farming groups may be suitably explored to enable sustainable growth.

The interest in organic farming is mainly revolves around the positive effects on the environment and ensuing sustainability for a longer run. However, uncertainties are there about the associated socio-economic impacts towards employment due to decline in total volume of crop production. However, organic farming has the capacity to provide positive outcomes not only environmental point of view but also in social grounds like new job opportunities, income generation and rural development. Replacing synthetic chemicals in organic agriculture supposed to resulted in higher demand for labour than in conventional agriculture and therefore, may improve rural employment and also to run small farm entrepreneurship by the young and educated youths. Employment opportunity also lies in small and large-scale organic food products industries. Further, organic farming and integrated farming also contribute to rural economies through sustainable and holistic development of rural livelihood. New employment opportunities may be escalated in organic based farming, processing and related services, and these are already evident in the growth of the organic sector. In addition to tackling environmental pollution and low-input dependent agriculture, these farming systems can bring benefits both to the economy and the social cohesion of rural areas.

8. Future of organic farming in India

Increasing awareness about the environmental and health benefits of organic foods among elite Indian population is setting the pace of growth of domestic market in India, which is highly essential for success of organic movement in India. Traditionally in many parts of India organic farming practices are followed by default, hence there India is having tremendous potential for organic farming and become a key player in the international market of organic produce. Keeping in view the growing demand for organically grown produce both in domestic and international market, implementation of innovative technologies will ensure economically viable organic agriculture and promote adoption organic farming by millions of common farmers of the country.

Integrated farming systems (IFS), those combine various interdependent components such as rice, fish, poultry, horticulture, agroforestry etc. provides unique opportunity to recycle the bio resource generated from one component by another and hence ensure organic production and practice. These organically maintained IFS apart from ensuring livelihood security of small and medium farmers of India also help them generate extra revenue. Organic rice–fish farming is found profitable, eco-friendly and less energy intensive.

9. Guidelines and standards of organic farming

Certification of organic agricultural produces is as important as production or cultivation methods to be followed for the same. Farmers can grow organic produces with a hope to get more remuneration than usual practice, for that it is much relevant to know the certification process. For the entrepreneurs dealing with organic farm produces should get a complete knowledge about the guidelines and standards to make their produces certified and labelled from competent authority. Organic farming certification in India is monitored by the National Programme for Organic Production (NPOP), under the authority of The Agricultural and Processed Food Products Export Development Authority (APEDA), Ministry of Commerce & Industry (GOI). The NPOP provides the details of standards for different aspects like organic production, systems, criteria and procedure for accreditation of Certification Bodies, the National (India Organic) Logo and the regulations associated (https://apeda.gov.in/apedawebsite/organic/index.htm). The standards and procedures have been formulated in harmony with other International Standards *viz*. USDA-National Organic Program, that ultimately regulates import and export of organic products. Farms that have received Organic Farming Certification and strictly following the rules/norms specified by the NPOP, will be permitted to use India Organic logo on the produce. The following methods are existing for certification of organic produces:

- **Third Party Certification**- Specially meant for export-oriented of organic products, involves more certification fees, regulated by NPOP.
- **Participatory Guarantee System (PGS)**- This is meant for organic produces for domestic consumption, accessible for small and marginal farmers who are interested to grow food organically. The is rather economic organic certification system and farmers can participate in the process and guarantee for the quality.
- **Alternative Certification Options**: This is not issued by public organic certification agency, but it follows mutual understanding between producer and consumer regarding food quality.

10. Conclusion

As per the scientific findings rice performs well under organic production system, although a set of constraints including nitrogen stress at critical growth stages. Additionally, the unavailability of rapid mineralization of nutrients supplied through organic amendments, lack of suitable varieties, intense crop–weed competition and pest management remain some challenges to actualize the potential yield under organic cultivation. High-value crops growing in a confined area with best possible care are often considered suitable for organic cultivation. Further development of rice varieties responsive to organic nutrient inputs, resistance to diseases/insects and having better weed competitiveness can determine the success of organic cultivation. Emission of greenhouse gases (GHGs) in organic rice fields can be better managed with appropriate water management and proper choice of appropriate inputs. Overall organic cultivation, as a form of low-input agriculture may create win-win situation. However, research gap still exists for a holistic understanding of the well performance of an organic rice system as a sustainable practice. Meanwhile, practicing organic farming following a collective or cluster approach will provide a great momentum to organic farming especially in rice growing areas of eastern India.

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Chapter 13

Post-harvest and Processing Technologies for Rice products

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Abstract

Rice is one of the world's most popular staple foods. It is still milled in most parts of India using traditional methods. There are a variety of processing methods and equipment to choose from. There are also several cutting-edge facilities that produce high-quality rice. Other methods of processing and storage, such as parboiling, drying, and storing, are used in a variety of ways, resulting in a wide range of product quality and market pricing. When compared to white rice, the by-products of the rice milling process have a lot of nutrients. By-products of the rice business include rice straw, rice hull, broken rice, rice germ, rice bran, rice bran oil, and wax. These by-products are typically used for basic uses in their original form, but they can now be used as raw materials for various value-added research or in food applications with beneficial properties. The purpose of this chapter is to go through the basics of rice processing and by-products, as well as current and emerging new technologies such as extrusion, canning, fermentation, etc., used in the value addition of rice and rice by-products.

Keywords: Parboiling, drying, extrusion, fermentation, emerging technologies, value-addition, rice by-products

1. Introduction

Rice is India's second most significant food crop and the world's largest producer, with 121.46 million tonnes produced during 2020-21. India is the world's leading exporter of rice in terms of volume. As of 2020, India's rice exports amounted to 19,000 thousand tonnes, accounting for 39.32 percent of global rice exports. India's yearly domestic consumption is at 100 million tonnes, or around 80% of the country's total production of 120 million tonnes. The Indian government has a requirement of 11.5 million tonnes of operational rice and two million tonnes of strategic rice reserves. India's rice is the country's fourth most significant crop. While overall rice production is projected to be around 1.5 million tonnes, white rice is consumed in the vast majority of cases. In fiscal year 2021, India exported rice worth roughly 653 billion rupees. This represented a huge rise over the previous year's exports, which totalled over 454 billion Indian rupees. The Indian rice industry's key challenges are a lack of suitable land for production and continuous and reliable irrigation. (https://pib.gov.in/PressReleaseIframe).

India is the world's only country that grows two crops each year. Rice is farmed in India's southern and western areas, which are also the favoured locations for the production of rice-based products. The technology of rice cultivation does not end with paddy harvesting. Post –harvesting procedures, as well as storage, are just as important as cultivating the crop because they determine the quantity and quality of paddy/rice. After the crops have been harvested, careful attention must be made to how they will be handled. If not, the manufacturers may suffer a significant loss. Cleaning, grading, drying, storing, processing (parboiling, milling), packaging, transportation, marketing, and these are all part of the post-harvest process. A good post-harvest system strives to reduce losses as much as possible.

An effective post-harvest system attempts to reduce losses, hence assuring food security and increasing income, which is critical for small and medium farmers, especially in developing nations. The efficient utilization of rice by-products is also critical for the system's economy and long-term viability. It is crucial to remember that food that has not been adequately processed or stored contains a lower nutritional value than the properly processed food. This has a direct impact on food and nutritional security.

The goal of this chapter is to cover the fundamentals of rice processing and by-products, as well as present and emerging novel technologies. This chapter explores into the specifics of the many technological interventions utilized in the processing and value addition of rice and its by-products.

2. Post-harvest processing of rice

Paddy is normally harvested with a moisture level of 14 to 22 percent (wet basis). When paddy is harvested with combines in developed countries, the kernels are mechanically stripped from the rice stalks or panicles. From the combines, the harvested paddy is subsequently dumped into a truck. The completely loaded truck of rough rice is then transported to the rice mill, where it is further dried to a moisture content of 12.5 percent to reduce mould development and respiration rates (Dillahunty et al. 2000), as well as to hinder the growth of fungus and insects (Chen et al. 1997).

2.1 Drying of rough rice

For safe storage and milling, the recommended moisture content for paddy harvesting is 22-24 percent, 12 percent, and 14 percent, respectively. The moisture content must be reduced gradually and under regulated conditions. Even though LSU dryers are used to dry paddy in most modern commercial rice mills, open sun drying is still the most frequent way of drying paddy in underdeveloped nations. According to two recent studies, poor drying causes losses of 0.8 and 0.23 percent (Leon MA et al. 2002) Traditional drying procedures, on the other hand, are expected to result in even more losses. To counter the drawbacks of open-air drying, certain batch/continuous methods have been developed.

2.2 Storage of paddy/rice

In India, food grain storage has been an issue. Poor post-harvest management causes large amounts of produce to be lost. It is also claimed that food grain transportation has not been optimised, resulting in significant losses even before the crop reaches the FCI godowns. Further losses occur within the godowns as a result of rats or poor storage methods (Pillai and Kumar, 2018)

According to a study conducted by ICAR-CIPHET in Ludhiana in 2012, the total loss of paddy in storage is roughly 1.28 percent. There is a considerable reduction in the storage loss estimated in this study as compared to those (2-6%) earlier reported by FAO (1980). Traditional paddy/rice storage structures composed of straw, bamboo, wood, mud, and other materials are quickly disappearing. Grain storage in gunny sacks in a corner of the living room, as well as underground storage, are both frequent options. The modern category includes silos and godowns with good structural and operational features.

Farmers in India are also adopting advanced technologies such as hermetic storage and mechanised metal containers. In comparison to heap grain storage, on-farm grain storage, such as cover and plinth storage (CAP) technology, has advanced significantly since its introduction. According to agricultural extension studies, metal bins are the most often utilised because of their inexpensive cost, ease of production, and utilisation (Bhardwaj and Sharma 2020).

Other techniques include airtight (hermetic) storage, low-temperature storage, low-temperature and dehumidified storage, high-temperature storage, and storage under modified/controlled atmospheric conditions. The modified environment (airtight) storage developed by the IRRI in the Philippines can be regarded a low-cost option for storing seeds for a longer period of time (Luh BS 2013). It is necessary to develop low-cost, appropriate technology for safe paddy storage at the farm level.

2.3 Cleaning of rough rice

Extraneous elements such as straw, chaff, dust, impure grains, sand, and soil clods make up 8-10% of paddy after threshing. To obtain the Government's minimum support price (MSP) in the market, grains must be cleaned adequately to meet the quality standards. The manual winnowing method is still employed for paddy threshing, which is not very successful but is a time-consuming and arduous process. Commercial seed cleaner cum graders are available, however they are frequently out of reach for most farmers due to financial constraints. Improved cleaning fans, winnowers, pre-cleaners, De-stoners and cleaner cum graders, both manual and power operated, have been developed, manufactured, and used for food grains by several research organizations (Fig. 1).

2.4 Dehulling or shelling of rough rice

Brown rice is made from rough rice that has been dried to a moisture content of around 12.5 percent and then dehulled to remove the hull (Fig.2.). The next phase is brown rice milling, which consists of a set of operations that remove the embryo and a portion of the bran from brown rice kernels, resulting in ‘milled rice’ or ‘polished white rice’. However, some kernels tend to crack during milling. As a result, the milled rice fractions contain both entire and broken rice kernels. Using grading equipment such as a length grader, the whole kernels are sorted from the fragmented ones. Broken kernels are often crushed into flour, which can then be used in a variety of ways, as explained later in this chapter.

2.5 Parboiling of paddy

The technique of heating paddy before milling is known as parboiling. Paddy is normally soaked in water for a long time before being steamed, dried, and hulled in this process. The process of parboiling has various advantages. It decreases grain breakage during the milling process, resulting in a higher head rice yield (HRY), as well as improved micronutrient content over polished raw rice. Parboiling also improves the quality of cooking and eating, enhances the quantity of rice bran oil, and extends the shelf life by reducing infection during storage. Because parboiling is so widespread in India, the majority of parboiling research and development has taken place here. The widely used CFTRI method of parboiling rice yields excellent parboiled rice (Schramm RC 2010)

2.6 Rice milling

Hullers are extensively used milling devices, particularly for tiny paddy volumes. These machines, however, are considered wasteful because they shatter a large amount of rice and do not have a way to separate the husk and bran. If purchased separately, husk and bran can be used for a variety of purposes. In current rice milling equipment, however, the ability to get husk and bran separately is available. Other machinery, such as pre-cleaners and husk aspirators, can also increase the performance of the rubber roll sheller and polisher in a modern rice mill. A large investment is usually necessary to construct a contemporary rice mill, and small millers will not be able to replace their hullers with modern rice mills right away. However, a compromise can be recommended for huller owners, which is known as ‘modernised huller’. Small millers are also becoming more interested in single-pass rice mills, which require less capital.

3. Rice processing and value addition

Any cereal grain would require some processing in order to make it easily digestible and acceptable for use in a variety of food applications. The initial stage would be to remove any foreign objects, trash, or contaminants or broken glass utilising a variety of specialized machinery. Cleaning is followed by moisture conditioning and tempering, which are standard pre-treatments for any cereal, including paddy (Kent NL 1994).

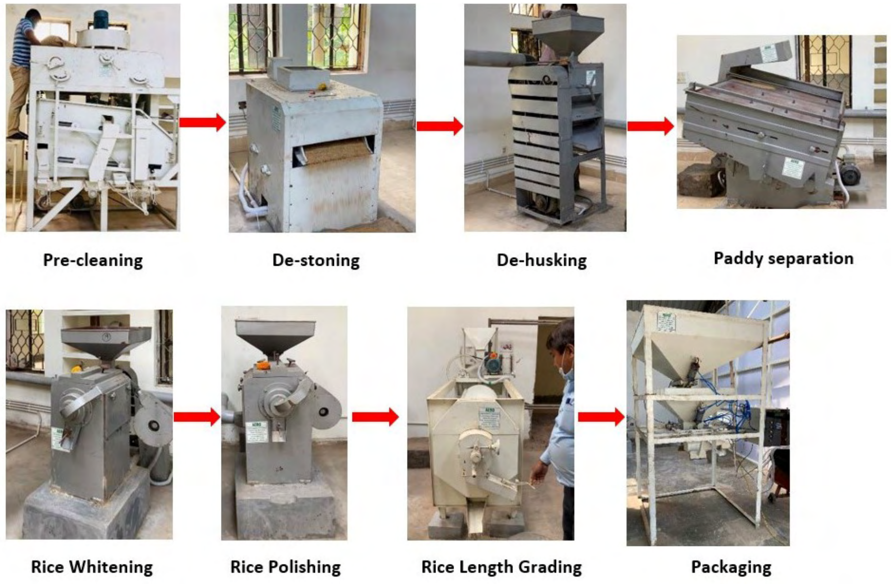

Figure 1. Flowchart of modern rice milling process (source: authors' own depiction)

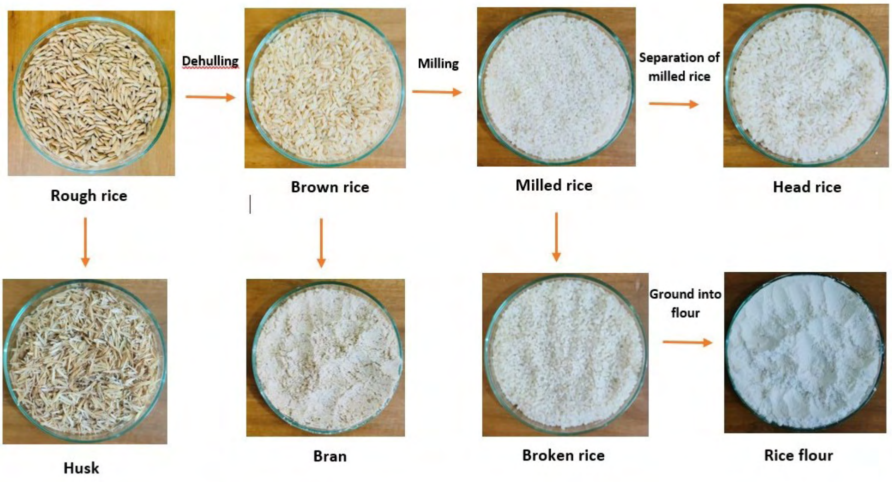

Figure 2. Rice post-harvest processing steps (source: authors' own depiction)

Processed foods account for over 32% of the total Indian food market. Processed food accounts for 14% of India's manufacturing GDP and 13% of the country's total export commodities (IBEF 2020). Rice and its processed products account for a significant portion of the global food market. Rice was only consumed freshly prepared in the form of boiling rice in the past due to a lack of knowledge, infrastructure, and technology. The scenario has changed as a result of latest improvements in food science and technology, with the emergence of various new-generation post-processing and value-adding technologies. Canning, freezing, extrusion, fermentation, and other processing procedures are used in this industry.

Previously, the focus was solely on rice safety and shelf-life extension, leading to the development of various post-harvest technologies such as drying and parboiling. Consumers increasingly seek rice-based goods that are nutritious, wholesome, ready-to-cook, and ready-to-eat, as well as being safe. In order to meet these expectations, certain thermal and non-thermal processing technologies have been developed that are more effective than raw rice at maintaining nutritional content or giving nutritional quality through fortification (Gantsho KA 2014).

3.1 Need for processing and value addition of rice

Correct paddy drying, hulling, and milling with complete removal of the bran, as well as proper packing and storing of polished rice, are all important steps in improving rice storability. The fibre component of rice is fully removed during polishing since it is not suited for storage, which causes rancidity to develop in brown rice, lowering the quality of rice grains for consumption. Improved processing and packaging technology may be used to transform them into shelf-stable, value-added commodities, allowing the most nutrients to be preserved.

Rice is one such basic food that is eaten by people all across the world. Rice cultivation could be made more profitable by processing it into numerous value-added goods. There is a lot of potential for producing different value-added goods, such as ready-to-eat, ready-to-cook dishes, instant health mixes, fortified rice products that are commonly fortified with micronutrients or tastes, and so on. Broken rice, which can be transformed into starch, rice flour, or rice powder, is becoming increasingly popular in the rice milling industry. Due to the general preference for unbroken rice kernels, the value of rice is increased with grain breakage reduction at harvest and postharvest (Prom-U-Thai et al. 2020). When compared to polished white rice, by-products of the rice milling industry such as straw, husk, bran, broken rice, rice germ, and wax contain significant amounts of nutrients such as cellulose, hemicellulose, and lignin, and can be used in value-added research for improved functional qualities in food applications (Esa NM et al. 2013).

Rice bran is the white endosperm of the rice grain's upper thin layers. It's produced as a by-product of rice milling and includes 14 to 15% crude oil. Simple solvent extraction or mechanical pressing can be used to extract the oil. Rice bran oil (RBO), one of the high-valued edible vegetable oils recommended by the World Health Organization, is widely consumed throughout Asia (Nayik et al. 2015). It's high in unsaturated fatty acids (oleic and linoleic acids) and dietary phytochemicals like Vitamin E, squalene, phytosterols, polyphenols, and oryzanol (Bagchi et al. 2020). Because of its palatability, plasticity, and spreadability, it is used in the food industry to make margarine and shortenings. It can also be used to boost the nutritional value of bread, cakes, noodles, pasta, and ice creams without compromising their textural and functional features (Upasana et al. 2021)

3.2 Rice, rice products, and their expanding demand

Rice is a distinctive cereal since, unlike other cereals, it is primarily consumed as 'table rice'. As a result, the milled undamaged rice kernels' physical integrity must be preserved. Rice kernels are primarily appreciated for their physical quality. Because of its economic importance, head rice or entire unbroken kernels always have a higher value than fractured equivalents, which are normally valued at 50 percent or 60 percent of that of the head rice. As a result, the overall goal of any post-harvest processing and milling sector would be to maximise head rice yield (HRY) by properly exposing the cereal to various processes such as drying, tempering, and storing prior to milling.

In recent years, the milling industry has seen an increase in demand for unused broken rice. This is owing to an increase in the number of patients diagnosed with celiac disease, an autoimmune genetic illness of the small intestine (Hartmann et al. 2006; Woodward, 2007), for which the only treatment is to follow a gluten-free diet. Rice is inherently gluten-free and hypoallergenic, making it an excellent choice for gluten-free food compositions. Furthermore, broken rice kernels from milling businesses are widely employed in the formulation of infant foods, the production of ready-to-cook products such as pasta and noodles, and a variety of bread and fermented products after being converted to rice flour. It is also being used in the production of edible films and cutlery, among other unique applications.

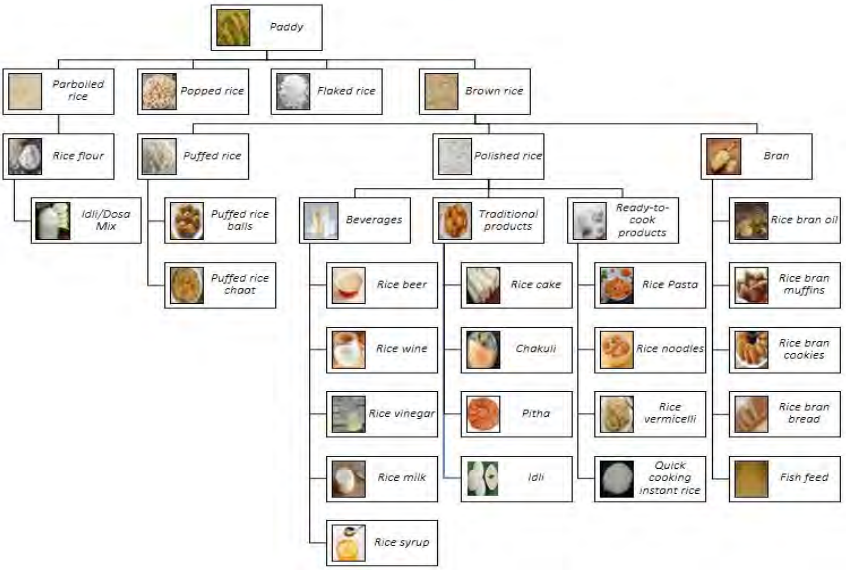

Figure 3. Processed value-added products of paddy (source: authors' own depiction)

The pet food industry also makes substantial use of broken rice kernels. The sale of cracked rice kernels will benefit as a result of this. These are also employed in the development of beverage products in breweries. Other uses for rice milling by-products include feeding hulls to cattle, poultry, and fish, using husk as plant bedding, and using hulls as a combustion material during paddy parboiling. Used to clean up huge oil spills as well. Rice bran is used to obtain rice bran oil, and defatted rice bran is combined with husk to make animal feed (Bodie et al. 2019).

Puffed rice (*Murmura*) and parched or flaked rice are two popular or well-known processed items made from paddy or rice (*Chuda*). Rice beverage (*Handiya*) and fermented rice (*Pakhala bhata*) are two traditional rice-based popular products in the North Eastern states of India. However, they do not have a lengthy shelf life, and the majority of them must be consumed within a day in the case of fermented rice and a week in the case of Rice beverage. To extend the shelf life of such nutritionally dense traditional popular processed foods, development and standardization of processing and packaging technologies are necessary.

4. Processing methods of paddy

4.1 Primary processing methods

Harvesting, cleaning, and milling are the three main steps in the paddy processing process. When the rice grains are mature but not entirely matured, paddy is harvested. The grain is separated from the husk, which is the grain's outer shell, in the next stage. According to the husk, the grain can be divided into two categories: broken and unmilled. The next step is to remove the bran, which is the grain's outer layer and where the majority of the nutrients are found. This is accomplished by a variety of processes, including washing in water, washing in alcohol, and using mills. Separating the husk and bran from the paddy is the next phase in the processing, which can be done using a variety of methods including flotation, centrifuge, and screening. After that, the husk and bran are removed, leaving the endosperm, or grain kernel. The bran and germ are removed from the rice grains, which are separated into the head and broken kernels, respectively. The rice grains are separated into their sections, including the bran, germ, and endosperm, after the paddy has been cleaned.

4.2 Secondary processing methods

4.2.1 Puffing and Popping

Puffing refers to the quick expansion of pre-gelatinized rice grains, whereas paddy popping refers to the rapid expansion of paddy grains. Puffed rice retains its shape except for a significantly bigger volume growth, whereas popped rice has an uneven shape similar to popcorn made from maize because it is subjected to expansion while the husk and bran remain intact. The kernel bursts when subjected to extreme temperatures. For the production of puffed and popped rice, both modern and traditional technologies are available. The main raw material in the production of various value-added processed products, such as crisped rice, is puffed and popped rice (Fig. 3).

4.2.2 Flaking

Flaked rice is made by flattening and rolling parboiled paddy with rollers and flakes, then allowing it to dry entirely. These are commonly referred to as ‘poha’ and are typically eaten for breakfast in almost all Indian states. Sand residue is a concern with traditionally produced sand roasted flaked rice. As a conduction medium, roasting in common salt turned out to be the best option. Dry roasting of flaked rice is done in a developed agitated dry roaster in the temperature range of 260 to 340°C with a scientifically built combination as per central composite rotatable design combination, with time ranging from 20 to 60 seconds (Kumar and Prasad 2017). Flaked rice comes in a variety of thicknesses for different uses and applications, which are mainly accomplished by adjusting the pressure exerted during the flaking process. Due to its reduced thickness compared to whole rice, flake rice absorbs a considerable volume of liquid as well as tastes. They are also employed in the creation of a variety of snacks, sweets, and even as a side dish element in recipes (Fig.3).

4.3 Tertiary processing methods

4.3.1 Canning

Food pathogenic microbes that may endanger public health, as well as an enzyme that causes quality deterioration during storage, are destroyed by canning, which is a technique that involves heating food in hermetically sealed containers for a predetermined time-temperature combination to destroy pathogenic microbes that may endanger public health and an enzyme that causes quality deterioration during storage. Food goods have a longer shelf life as a result of it (Gerdes and Burns, 1982).

Rice can be made into a variety of canned rice products, including soups, baby meals, flavoured or plain cooked rice, rice pudding, and so on. The most prevalent packaging materials for canned rice products are lacquered tin cans and flexible retort pouches. Rice is usually pre-processed in a suitable manner, such as parboiling, to preserve the integrity of the rice kernels before being canned. Rice kheer, fried rice, and ready-to-eat rice mix with curries are examples of dry items that can be canned._

4.3.2 Extrusion

Extrusion cooking is a multi-step, thermo-mechanical process. It is also the most versatile food processing procedure for improving nutritional, functional, and sensory qualities in products. Several product operations, such as mixing, heating, frying, shearing, and shaping, can be controlled with this technology. Due to its colour, bland flavour, and processing qualities, rice is one of the most common cereal crops for the manufacturing of ready-to-cook (RTC) items such as pasta, noodles, ready-to-eat (RTE) morning cereals, modified starch, weaning foods, snack foods, pet foods, and dried soups (Dalbhagat et al. 2019). The main advantages of this procedure over others include the ability to continually mix, heat, and devolatilize while managing critical process parameters to generate a high-quality end snack, as opposed to older methods.

4.3.3 Pulverization

Broken rice obtained from milling businesses is typically transformed into rice flour or rice powder, which has a higher market price than broken rice. This could be made from either brown rice or white polished rice. Rice starch, on the other hand, is made by steeping rice in lye (Vaishnavi Devi N and Sinthiya R 2018). Rice flour has been used in meals as a gluten-free alternative for wheat flour. Rice flour can also be used as a thickening agent in recipes that need to be refrigerated or frozen (Fig. 3).

4.3.4 Fermented beverages

Rice beer, rice wine, and rice vinegar are examples of rice fermented beverages. In order to improve fermentation-related techniques, it is necessary to develop energy-efficient and environmentally friendly sustainable procedures. Traditional heat treatments have traditionally been utilised in food fermentation; however, the organoleptic characteristics of the treated products can be altered (Koubaa et al. 2016). These fermented beverages can be made entirely from rice. Rice beer and rice wine have alcohol concentration of 12-13 percent and 18-25 percent, respectively (Bhuyan et al. 2014) Traditional fermented products are considered to be low-cost, provide a source of income, and assist the economy in conserving foreign exchange. 60% of the rice sold in the domestic market is utilised for table rice, around 25% for the industrial market and various processed products, and about 15% for beer manufacturing (Anal 2017) (Fig. 3).

4.3.5 Pre-cooked or instant rice

Customers' demands influenced the development of several current technologies. Instant rice is just dried rice that has been pre-cooked and gelatinized. The integrity of the rice structure is preserved during drying, and it is subsequently packed in the same manner as regular rice. The benefit is that it only takes 5 minutes to prepare. Freeze-dried rice and canned rice are two other simple rice options. Dry soup mixes, rice puddings, casseroles, flavor-coated free-flowing rice, and other dry prepared mixes are just a few of the uses for quick-cooking rice forms (Fig. 3).

The majority of the processing is based on hydrothermal treatments of various rice grains. The reorientation of starch granules, for example, has occurred. Because of its lightness and crispness, puffed rice is particularly popular as a breakfast component in many eastern states of India. Popped rice is also a popular snack dish. It is extremely healthy, including more antioxidative chemicals than other foods.

4.3.6 Oil Extraction

Rice bran, a high-nutrient by-product of the rice milling industry, is used as animal feed instead of being exploited for oil. Rice has a low oil content in comparison to carbohydrates and protein, however it has been discovered that oil contributes to the nutritional, functional, and sensory qualities of rice. It is also called rice bran oil and has been extensively used in Asian countries. Rice bran wax is a by-product of oil extraction that is used to make emulsifiers, polishes, cosmetics, candles, and a variety of other industrial products (Fig. 3).

5. Conclusion

On a daily basis we all eat processed foods. Processing agricultural output has become a need of our daily lives in today's era of agricultural engineering interventions. The food processing industry has faced significant hurdles in recent years, as food safety regulations have become increasingly severe around the world. This has prompted necessary technological changes and advancements in the industry. It was considered that all of these advancements needed to be built on a solid foundation of core processing technology.

It is necessary to investigate the possibilities of developing more high-value-added goods from rice and its by-products in order to raise marketability of rice at the export level and hence the grower's revenue. There is also a need to scientifically screen locally grown varieties to see if they are suitable for conversion into other high-value-added products, in order to improve their market popularity and demand. There have not been many studies in this field, however a good scope lying for research and technological inventions by the scientists of relevant fields.

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Chapter 14

Greenhouse gases emissions from rice production systems and mitigation strategies

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Abstract

Global warming is an issue in present day climate change challenges. Agriculture contributes to global warming by the emissions of three major greenhouse gases (GHGs) namely, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). This sector contributes about 20% of the total GHG emissions, globally. In agriculture, rice paddy is considered as one of the crucial drivers of GHGs emissions. This system contributes about 11 and 30% of global agricultural N_2O and CH_4 emissions, respectively. Aerobic and upland agricultural systems primarily emit more N_2O, whereas flooded/submerged rice and other wetland ecologies emit higher CH_4 than N_2O. When comparing different crops in India, GHGs emissions from rice is approximately four time higher than other crops like wheat and maize. Several factors are responsible for the higher GHGs emission from rice soil, such as rice straw incorporation, use of nitrogenous fertilizers, submerged/flooding field-conditions, etc. Rice straw addition to the soil provides enough easily available organic carbon (C) which trigger the immobilization of other soil nutrients and also increases the methanogenic activities. Several studies reported that different modes of rice straw application in field like, direct incorporation of straw in soil, mulching, burning of straw on-field, straw-composting increase both CH_4 and N_2O emission in rice-based cropping systems. Specifically, the flooding conditions in the rice field is favourable for the activities of methanogens resulting higher CH_4 production as compared to the aerobic conditions. Therefore, GHGs emissions in rice-based systems could be reduced by the modification of irrigation scheduling, tillage manipulation, managing organic matter addition, balanced-fertilizer application, selection of suitable crop varieties, and cropping sequences. Major mitigation cum adaptation strategies to reduce the GHGs emissions from rice-based cropping systems are (i) adaptation of rice-pulse cropping system instead of rice-maize to reduce the CO_2 emission by 30-35%; (ii) alternate wetting and drying, intermittent irrigation and controlled irrigation in the rice growing period; (iii) applications of phospho-gypsum (2 t ha^{-1}), basic slag (1 t ha^{-1}), and biochar (5 t ha^{-1}), once in three years; (iv) use of industrial waste as soil amendments to reduce methane emission; (v) adaptation of direct-seeding of rice instead of conventional puddled transplanted rice. Thus, proper management is needed in rice-based systems to reduce the GHGs emission.

Keywords: Greenhouse gases, mitigation options, rice, adaptation strategies

1. Introduction

Global warming is caused by the increase of atmospheric greenhouse gases (GHGs) concentration that leads to ‘enhanced greenhouse effect’. Increasing temperature of earth atmosphere significantly impacted the crop productivity. Three major GHGs i.e., carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are emitted from agricultural systems to atmosphere (Bhattacharyya et al., 2019). The agricultural sector contributes around 20% of the total GHG emissions, globally. The CO_2 mainly emitted through the soil organic carbon decomposition; CH_4 from submerged or flooded rice field and due to cattle enteric fermentation; and N_2O due to the application of nitrogenous (N) fertilizer during the crop growth stages (IPCC, 2014). Rice is the staple cereal crop, and it is grown in 153 million hectares of area annually which comprising 11% of total arable lands worldwide (FAO, 2011). India is the largest rice producing country in Asia and rice cultivation occupies approximately 44 million ha of land. Rice production in India accounts for 20% of the total production in world. There is a need to increase the rice production (from 116 million tonnes in 2021 to 130 million tonnes of milled rice by 2030) to ensure the food security as the demand of rice is predicted to be increased up to 24% in the next 20 years, globally (Liu et al., 2015). However, rice paddy is considered as one of the crucial sources of GHGs emissions as it contributes about 11-12 and 28-32% of global agricultural N_2O and CH_4 emissions, respectively (IPCC, 2014, 2021). The global warming potential (GWP) of CH_4 and N_2O is 27.5 and 275 times more than the CO_2, respectively (IPCC, 2021). Aerobic and upland agricultural systems primarily emit more N_2O, whereas flooded/submerged rice and other wetland ecologies emit higher CH_4 than N_2O. When comparing different crops in India, GHGs emissions from rice is approximately 3-5 times higher than other arable crops like maize, pulses and wheat (Linquist et al., 2012).

2. Greenhouse gas production and emission from rice-based system

Agricultural soils particularly rice-based cropping systems contribute more towards the greenhouse effect primarily due to the production and emission of three major GHGs. In rice soil, CH_4 is produced in anaerobic environment by the activities of methanogens (methane producing archaebacteria). Anoxic/anaerobic conditions favour the performance of methanogens resulting more CH_4 production as compared to aerobic/oxic environment (Bloom and Swisher, 2010). In the flooded/submerged rice field condition, the redox potential declines sharply resulting a suitable environment for CH_4 production. The assimilated carbon by plants which is needed is generally released to the soils through root exudation. Part of those labile carbon also sometime converted to CH_4 through methanogenesis (Naser et al., 2007). Similarly, the N_2O is generated through microbial mediated processes like nitrification and denitrification. Application of nitrogen fertilizer and the soil moisture are the important factors for determining the rate of N_2O emissions from rice-based cropping system. The CH_4 and N_2O are primarily produced in soils then after production, those gases are transported to the atmosphere through the rice aerenchyma. The GHGs emissions from rice field depend on different crop management like irrigation scheduling, tillage operations, dose and method of N-fertilizer application, and use of organic manures. Thus, modification of those agronomic practices offers the possibilities for reduction of GHGs emissions from rice-based cropping system (Hussain et al., 2015).

Rice straw (RS) is generated after the harvesting of rice grain which either burned on the field or left openly could be utilized alternatively as animal fodder, thatching, mushroom production, composting, etc. The straw burning is not recommended for its negative effect on air quality, soil-nutrient losses, and damage to animal and human health (Bhattacharyya et al., 2021). Straw incorporation to soil supplies sufficient readily available organic carbon which favour the immobilization of other plant available nutrients and also increases the methanogenic activities (Bhattacharyya et al., 2012, 2020). Several studies observed that different use of rice straw like, direct RS incorporation to soil, mulching, straw burning, RS composting enhance both CH_4 and N_2O emission over control treatments (Table 1). The mitigation options that hamper the crop yield is not acceptable by the farmers; therefore, mitigation option with yield benefits or sustainability needs to be encouraged. The alternative use of straw as straw-mushroom-spent compost/ straw-compost to soil in rice-green gram cropping system could be adopted due to dual benefits; one to avoid open field burning of straw and second one is that it can moderate the negative effect of climate change by sustaining the crop yield (Dash et al., 2021).

The continuous flooding conditions in the rice field facilitates the activities of methanogens resulting higher CH_4 production as compared to the aerobic crops. The CH_4 emission was lower (119.7 kg ha^{-1}) under alternative wetting and drying condition in rice system compared to continuous flooding conditions that emits higher CH_4 (154.0 kg ha^{-1}) (Table 1) (Oo et al., 2018). However, the alternative wetting and drying conditions enhanced the N_2O emissions as compared to flooding rice field. Similarly, when comparing different rice-based systems, rice-rice cropping system emitted higher CH_4 and N_2O as compared to other rice-based systems like rice-fallow, rice-potato-sesame, rice-maize-pigeon pea, rice-sunflower-green gram, rice-chickpea-green gram (Table 1). Therefore, several efforts need to be taken to reduce the overall GWP by decreasing the CH_4 and N_2O emissions from rice production systems. Major GHGs mitigation options and adaptation strategies to reduce both CH_4 and N_2O are briefly described in the next section.

Table 1. Greenhouse gas emissions from rice-based cropping systems under different management practices.

Sl. No.	Cropping System	Management Practices	CH_4 emission (kg ha$^{-1)}$	N_2O emission (kg ha^{-1})	GWP (ton CO_2 ha^{-1})	References
1	Rice-fallow	Control	90.60	0.58	2.27	Liu et al., 2015
		NPK	109.51	0.81	2.74	
		NPK + straw burning	94.23	1.38	2.36	
		NPK + straw mulching	394.06	1.19	9.85	
		NPK + straw mulching + Green-manuring	375.46	1.26	9.39	
2	Rice-rice	Control	69.70	0.23	1.60	Bhattacharyya et al., 2012
		Urea	92.60	1.00	2.21	
		Rice straw + urea	115.40	0.84	2.57	
		Rice straw + green manure	122.70	0.72	2.78	
3	Rice-rice	Control	260.00	0.39	-	Koga and Tajima, 2011
		Rice straw incorporation	790.00	0.39	-	
4	Rice-rice	Alternative wetting and drying irrigation	119.70	1.23	4.44	Oo et al., 2018
		Continuous flooding	154.00	0.61	5.42	
5	Rice-green gram	Rhizobium	63.1	1.83	2.31	Dash et al., 2021
		Zero tillage	62.7	1.27	2.14	
		Mushroom waste	65.2	1.54	2.29	
		Biochar	64.7	1.54	2.27	
		Rice straw compost	68.5	1.59	2.39	
		Methanotroph formulation	59.5	1.54	2.13	
		Phosphogypsum	61.5	1.66	2.22	
		RDF	63.5	1.8	2.31	

6	Rice-rice	RDF	304.25	3.42	8.62	Datta et al., 2011
	Rice-potato-sesame	RDF	23.42	5.56	2.24	
	Rice-maize-pigeon pea	RDF	16.32	4.46	1.74	
	Rice-sunflower-greengram	RDF	15.55	4.68	1.78	
	Rice- chick pea-greengram	RDF	16.33	6.19	2.25	

3. Crop management options to mitigate GHG emissions from rice-based cropping system

The GHGs emissions in the rice fields can be reduced by the modification of irrigation scheduling, balanced-fertilizer application, managing organic manures, tillage activities, selection of less GHGs emitting crop cultivars, and cropping sequences. Several mitigation technology and strategies are described below to reduce the GHGs emissions from rice-based cropping system. The strategies of reducing CH_4 emission from rice are mid-season drainage; intermittent irrigation; improving soil organic matter; promoting aerobic decomposition og organic matter; straw incorporation to soil during off-season; adaptation of suitable rice cultivars with high productive tillers, more root-oxidation activity and higher harvest index; and application of farmyard manure (FYM) and biogas slurry instead of unfermented organic matter.

3.1 Modifying irrigation pattern

Proper water management is the important factor which control the GHG emission from rice-based cropping system. Several water managements options such as alternate wetting and drying (AWD), intermittent irrigation, regular drainage periods in mid-season, and controlled irrigation through the crop growth stages minimize the GHG emissions than the traditional flooded rice condition (Pathak et al., 2010; Hussain et al., 2014). Those can be adapted in varying climatic and soil conditions without hampering the crop yields (Table 2). The intermittent irrigation reduces the GHGs emission from 15-54% as compared to traditional flooded rice (Feng et al., 2013). Further, mid-season drainage could sharply reduce the GHGs emission up to 27-72% (Table 2).

Table 2. Greenhouse gas mitigation potential of different water management practices compared to conventional flooded rice.

Sl. No	Management practices	GHGs	Mitigation potential (%)	References
1	Intermittent irrigation	CH_4	38	Yagi et al. (1996)
		CH_4	15	Adhya et al. (2000)
		CH_4	26	Minamikawa and Sakai, (2005)
		CH_4, N_2O	34	Hadi et al. (2010)
		CH_4, N_2O	54	Feng et al. (2013)
2	Mid-season drainage	CH_4	50	Cai et al. (1997)
		CH_4	43	Corton et al. (2000)
		CH_4	36	Zheng et al. (2000)
		CH_4	64	Minamikawa and Sakai, (2005)
		CH_4, N_2O	27	Towprayoon et al. (2005)
		CH_4, N_2O	42	Zou et al. (2005)
		CH_4	37	Tyagi et al. (2010)
		CH_4, N_2O	72	Itoh et al. (2011)
		CH_4, N_2O, CO_2	33	Pathak et al. (2012)
3	Controlled-irrigation	CH_4, N_2O	67	Yang et al. (2012)
		CH_4, N_2O	27	Hou et al. (2012)
4	Water saving-irrigation	CH_4, N_2O	60	Win et al. (2015)

[Source: Hussain et al., 2014]

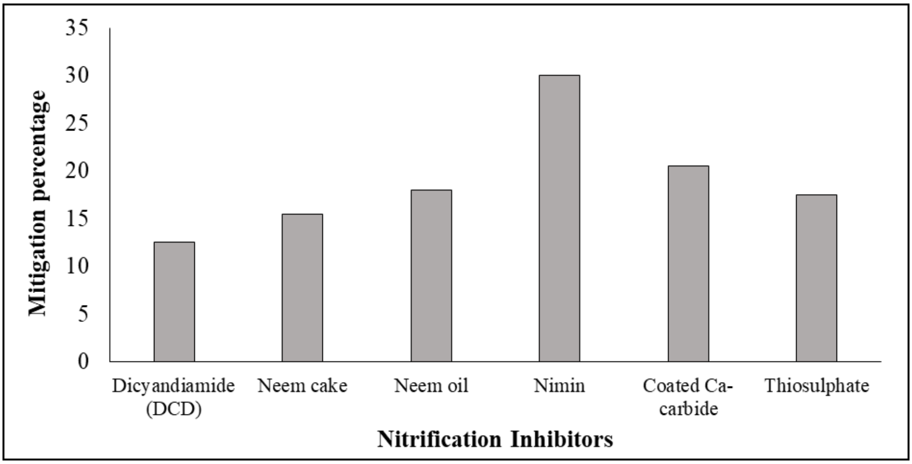
3.2 Direct Seeding of Rice

Direct seeding of rice (DSR) is a good option to mitigate CH_4 emission from rice system. Methane is emitted from rice soil when it is continuously flooded/ submerged during growth period in traditional (puddled) transplanted rice. However, the DSR can be grown as aerobic crop which does not require continuous submergence, thereby CH_4 production could be reduces drastically. As the DSR reduces the CH_4 emission significantly (16-54%) it considerable reduces the GWP, even up to 75% compared to the conventional transplanted rice system (Pathak et al., 2010).

3.3 Fertilizer management

Fertilizer management is the key driver of GHGs emissions from rice-based cropping systems. Primarily, the doses of N fertilizer influence both the CH_4

and N_2O emissions. Studies revealed that the higher doses of N application can decrease the total CH_4 emissions by 30-50% in rice (Yao et al., 2012). The higher N fertilizer application reduced CH_4 emission, but increased N_2O emission over control (where no N was applied) (Aulakh, 2001). It was also reported that 75% reduction of CH_4 and 58% increase in N_2O emissions in rice where N-fertilizer application rates were increased from 150 to 400 kg N ha^{-1} (Zou et al., 2005). In this context, the most successful management practices to reduce N_2O emission are site-specific N management and use of nitrification inhibitors (Figure 1).



[Source: Pathak et al., 2010]

Figure 1. Efficiency of nitrification inhibitors in mitigating nitrous oxide emission in rice-based cropping system

3.4 Use of rice straw amendments

Higher rice grain production leads to huge production of straw/residues which are mostly left/ wasted on the field. As the application organic manure is gradually decreasing, there is a need to recycle the straw to compensate the carbon losses from the fields. Moreover, open field rice straw burning by the farmers generates causes air pollution, GHGs emissions, and adversely affects the biodiversity. The alternative application of straw as straw-compost and field-incorporation enhances the CH_4 emission by providing the labile carbon as a substrate for methanogenic activity, however, those practices enhance the soil carbon-build up and sustain crop yield with moderate GHGs intensities (GHGI) (Bhattacharyya et al., 2019).

3.5 Use of industrial waste as soil amendments to reduce methane emission

Industrial waste like phosphogypsum (by-product of phosphoric acid industry) and basic slag (by-product of steel industry) are the specific soil amendments which could reduce the GHGs emissions from rice-based systems. The phosphogypsum (PG) suppresses the methanogenesis and reduce CH_4 production in rice ecology (Ali et al., 2015). There have been concerns about the PG use in agriculture because of the chances of heavy metals contamination in soil and subsequent uptake crops (Kumar et al., 2020). However, several studies reported that PG can be safely applied at 1 to10 Mg ha^{-1} basis under submerged soil conditions in neutral to alkaline soils (Nayak et al., 2013). Studies revealed that the use of phosphogypsum reduced both the CH_4 and N_2O emissions to 22.3 and 13.9%, respectively as compared to control treatment in rice (Malyan et al., 2021) (Table 3).

Like phosphogypsum, basic slag also significantly reduces CH_4 and N_2O emissions in different rice-based cropping system. Basic slag contains free and active oxides of silica, calcium, and iron. Iron (Fe_3^+) free oxides act as an electron acceptor and compete with H_2/acetate for anaerobic decomposition of organic matter, thus inhibit the methanogenesis resulting less CH_4 production in the anaerobic rice soils (Wang et al., 2018). Silica oxide present in basic slag mitigates CH_4 emission by enlargement of aerenchyma which increases oxygen transportation from the atmosphere to the rhizospheric region, thus enhancing CH_4 oxidation (methanotrophy) (Bhattacharyya et al., 2019). The several studies demonstrated that the application of both phosphogypsum and basic slag are good options for reducing GHGs emissions in rice production systems (Table 3).

Table 3. Mitigation of GHGs emission through the application of industrial waste.

Sl. No.	Treatment	CH_4 reduction (%)	N_2O reduction (%)	References
1	Phosphogypsum	22.3	13.9	Malyan et al., 2021
		6.4	7.5	Dash et al., 2021
		20.1	14.9	Ali et al., 2019
		61.8	-	Wang et al., 2017
		31.9	12.6	Ali et al., 2015
2	Basic slag	14.7	17.6	Ali et al., 2019
		42.5	-	Wang et al., 2017
		13.7	27.5	Wang et al. (2018)
		33.7	5.7	Ali et al., 2015

3.6 Adaptation rice cultivars with lower GHGs emission potential

Rice cultivars having shallow root systems, more productive tillers, higher root oxidation activity, better harvesting index, emit less CH_4 as compared to other rice cultivars. The adaptation of rice cultivars with less GHGs emission potential should be site specific. It is an easily adaptable option with existing varieties.

3.7 Introduction of short duration crop in cropping sequence

Introduction of short-duration crops/ vegetation between two successive major crops could be an option to reduce GHGs emission as well as to protect the soil from erosion. The short-duration vegetation also improves the soil quality by increasing the soil carbon contents. It also helps to enhance the soil water holding capacity which improves the performance of the soil microbial communities and help in the conservation of biodiversity.

3.8 Application of methanotrophs formulation

The CH_4 emission from rice-based systems directly influenced by the methanogens and methanotroph communities. The methanogens are CH_4 producing soil archaebacteria, which contributes approximately 14% of the total GHGs emissions in the soil environment (EPA 2006). Previously efforts on organic and inorganic nutrients management, use of soil amendments (like biochar, phosphogypsum and basic slag) have made to mitigate the CH_4 emissions from rice production systems. However, no long lasting, solution to mitigate the GHGs emission has yet been well established. Thereby, to enrich the rhizospheric soil with efficient soil methanotrophs (methane oxidizing bacteria) is one of the eco-friendly options to reduce the atmospheric CH_4 emissions from the rice soil (Cui et al. 2015). These methanotrophs act as bioremediating agents in CH_4-riched environments (like rice and other wetland ecology) and thus considered as an essential global CH_4 sink. Recently, Dash et al. (2021) found that the application of methanotrophs formulation reduced the CH_4 emission around 4.8-7.1% in rice-green gram cropping system. Apart from rice ecology, the methanotrophic endophytes also reduce CH_4 and CO_2 emission to 50-77%, respectively in peatlands (Goraj et al. 2013).

4. The strategies to mitigate GHGs emissions

Different field level mitigation cum adaptation strategies to mitigate GHGs emissions are follows:

(i) Adapting rice-pulse cropping system instead of rice-maize could reduce the CO_2 emission by 30-35% (Neogi et al., 2014).

(ii) Two to three days drainage in rice-paddy within the critical growth stages of maximum tillering and panicle initiation stages could reduce the CH_4 emission by 30-40% (Lu et al., 2000).

(iii) Retention followed by incorporation of rice straw at *kharif* season in lowland rice reduced the N_2O emission by 10% but increased the CH_4 fluxes by 8% (Bhattacharyya et al., 2012). However, it should be encouraged as this technique also has carbon sequestration potential in medium to long run.

(iv) Phase wise conversion of traditional puddled rice zone to direct seeding rice belt with suitable weed management (through selective-herbicides) and water regulation coupled with introduction of second-generation farm machineries to curtail CH_4 as well as N_2O emissions (Bhattacharyya et al., 2020).

(v) In eastern and north-eastern India, transplanting of older seedling (26-30days) of rice instead of younger seedling (8-15 days) has the potential to reduce GHGs emissions.

(vi) Paired row cropping with rice-rice-*Sesbania* (row-orientation) and *in-situ* green manuring (i.e.,incorporation of *Sesbania* at 25-30 day after sowing) could be adapted for checking GHGs emission instead of traditional green manuring (incorporation of 40-45 days' old *Sesbania* before the transplanting of rice) (Bhattacharyya et al., 2014).

(vii) Early planting reduces emissions. Methane emissions are noticed more in late-planted rice during the *kharif* season.

(viii) Micro irrigation systems (drip and sprinkler) if adapted could reduce all the three important GHGs emission from agriculture.

(ix) Applications of phospho-gypsum (2 t ha^{-1}), biochar (5 t ha^{-1}) and basic slag (1 t ha^{-1}), once in three years have the potential to curtail GHGs emission in rice-based production systems.

(x) Selective application of butachlor, carbofuran, and hexachlorocyclohexane, have the potential to reduce CH_4 emission from agriculture by dropping the redox potential of the soil and inhibiting the of methanogenic activities.

(xi) Adaptation of zero / minimum tillage reduces the N_2O as well CO_2 emissions compared to conventional tillage in the rice-wheat system.

5. Conclusion

Several mitigation options cum adaptation strategies needs to be adopted by the farmers to reduce the GHGs emissions from rice-based cropping system in India. Though rice behave as a passage to transport GHGs from soil to atmosphere, and the demand of the rice increasing day to day, thereby the farmers need to be adopted different management practices which not only reduced the GHGs emissions but also sustain the crop yield. The important adaptation strategies to mitigate the GHGs emission are adapting rice-pulse cropping system instead of rice-maize, modifying irrigation pattern, use of straw compost, application of industrial wastes like basic slag and phosphogypsum as soil amendments, cultivation of rice cultivars having low GHGs emission potential, etc. These strategies not only reduced the GHGs emission but also increased crop yield in rice-based cropping system.

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Chapter 15

Carbon management and greenhouse gas emission mitigation options for rice-based systems

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Abstract

Rice-based cropping system occupying an area of 50 Mha corresponds to 30% of global area is the food basket of south and south-east Asia. Rice being cultivated with supplemented nitrogenus fertilizer under anaerobic conditions releases three major greenhouse gases namely carbon ioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). For counteracting the global climate change, soil carbon sequestration is considered as a viable management strategy. However, the external carbon sources e.g. green manure, crop residues, farmyard manure drive the carbon sequestration at the cost of methane emissions from soil. However, selection of appropriate management straetigies is the key to carbon sequestration vis-à-vis GHGs emissions from soil. Various management strategies e.g. conservation agriculture, incorporation of crop residues, judicious application of fertilizers, integrated nutrient management, agroforestry, direct seeded rice, sorghum-rice crop rotation and biochar applicatons emerged promising. Present chapter deals with the major climate change issues and the strategies thereof for mitigation of global climate change mainly for rice based cropping systems. The economically viable and socially acceptable technologies need to be popularized among the rice growers as mitigation options with the concerted initiative of the government and other organisations.

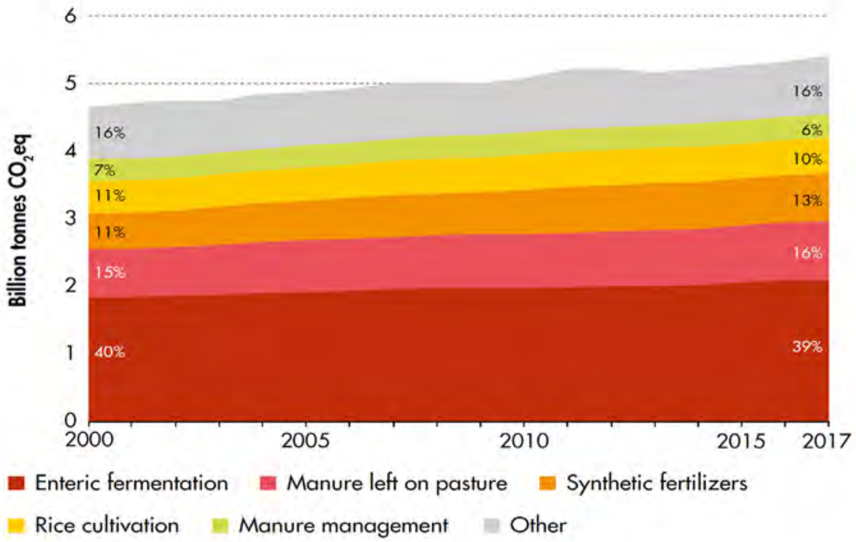
Keywords: Carbon sequestration, conservation agriculture, crop residues, crop rotation, GHG emissions

1. Introduction

"Climate change is no longer a future problem. It is a 'now' problem" says Inger Andersen, Executive Director (UN's Environment Programme). In 2019, global GHG emissions increased for the third year in a row, reaching a new high of 52.45 Gt CO_2eq without land-use change (LUC) emissions and 59.15 Gt CO_2eq with LUC emissions (UN-EGP, 2020). Capping the warming between (1.5°C - 2°C) by century end would be impossible to achieve without immediate, quick, and extensive reductions in GHG emissions(IPCC 2021).The emission of methane (CH_4), that account for nearly a third of greenhouse gas (GHG) emissions and 40%f the net warming impact among all anthropogenic activities considered as the second largest contributor to global warming after carbon dioxide (IPCC 2021). Continuous submergence, greater soil organic C content, and manuring in puddled soil, all help to increase CH_4 emissions; agricultural residue burning also contributes to global CH_4 budget. Anthropogenic CH_4 emissions being largely contributed by agriculture sector (Saunois et al. 2020). Enteric fermentation and manure management account for three-quarters of the total, whereas rice accounts for one-quarter of the emission. Unlike CO_2, little efforts has been given towards capture of methane from air, necessitating a more thorough examination of the viability of methane removal (Jackson et al. 2019). Rice (*Oryza sativa*) is one of the most widely planted crop in South Asia, accounting nearly 50 million hectares of land, or 30% of the global area (FAO, 2019). Rice is primarily grown under submergence that leads to emission of methane (CH_4) and nitrous oxide (N_2O) from nitrogenous fertilisers, resulting in greater GHG emissions than other crops (FAO, 2005). The GHGs emisssions calculated based on CO_2eq from different agricultural sectors when compared between the year 2000 and 2017, it was found there was 1% decrease in CO_2eq from enteric fermentation, 1% increase from manure left pasture, 2% increase from synthetic fertilizer, 1% decrease each from rice cultivation and manure management, and no change from other sources (Fig. 1).

In recent times soil carbon sequestration has gained a lot of importance as a climate change mitigation option. Because of therelevance in several soil functions such as soil fertility, crop productivity, and the global carbon cycle, management approaches that increase soil organic carbon (SOC) stock are gaining popularity. Capturing atmospheric CO_2 as a SOC could help to combat climate change (Liu, 2014). Improved SOC stocks may be aided by better residue management procedures. Ocko et al. (2021) underlined the importance of quick methane action in reducing midterm (2050) temperature. Reducing the emissions of methane from agriculture will be quite difficult, but it is essential too if we are to meet our low-warming-targets. Alternate wetting and drying of paddy fields as a water management strategy, can help to reduce CH_4 emissions, but the gains can be offset by increasing N_2O emissions (UN-EGP, 2021). According to Smith et al. (2008), Over 70% of the technical mitigation potential under agricultural sector is governed by tropical developing nations. According to feasibility studies and other estimates, the agriculture, forestry, and other land use sector having most cost-effective and short-term mitigation solutions (Smith et al. 2014). As a result,

FIGURE 66.
WORLD CROPS AND LIVESTOCK GREENHOUSE GAS EMISSIONS BY ACTIVITY



Source: FAOSTAT
Note: Percentages on the figure indicate the shares in the total.

https://doi.org/10.4060/cb1329en-fig66

Figure 1. World's crop and livestock greenhouse gas emission by activity (Source: FAOSTAT 2019)

initiatives for carbon management to minimise the GHG emissions from rice-dominated agriculture in south-east Asian countries might holds a crucial impact on reducing the global and regional implications of climate change.

2. Carbon and GHG emissions management options from rice-based cropping systems

2.1 Conservation agriculture

FAO defined Conservation Agriculture (CA) as "a farming system that promotes minimum soil disturbance (i.e. no tillage), maintenance of a permanent soil cover, and diversification of plant species". It promotes biodiversity to flourish and proper functioning of natural biological processes both above and below the ground surface, that helps in enhancing water and nutrient use efficiency and to assure sustained and improved crop production". Global coverage of conservation agriculture is expanding fast as a consequence of its tremendous benefits e.g. improving soil qualities, increasing crop productivity, supporting soil aggregation and physical protection of soil C found in micro-aggregates occluded inside macro-aggregates (Dalal and Bridge 1996; Somasundaram et al. 2017; Du et al. 2015; Conrad et al. 2018). Currently global cultivated land under conservation agriculture is reported as 180 million hectares (Kassam et al. 2019), but surprisingly it covers less than 5 million hectares in south Asia. Traditional farming mindsets, socio-economic situations, marginal farm holdings, management of weeds and residue, and lack of adequate farm machineries are all major barriers to its adoption.

Conservation agriculture could serves a a viable strategy to reduce GHG emission and to sequester soil carbon in rice based cropping systems. In rice, methane emission decreased by 56% after switching from conventional to zero tilled rice (ZTR) system (Tirol-Padre et al. 2016), whereas, no CH_4 emissions was detected in ZTR regardless of residue management in alluvial soil from northwest India (Sapkota et al. 2015). Similarly, Lal (2004) calculated that chisel ploughing (4.5–11.1 kg C ha^{-1}), mouldboard ploughing (13.4–20 kg C ha^{-1}), subsoiler (8.5–14.1 kg C ha^{-1}) and rotary hoeing (1.2–2.9 kg C ha^{-1}) create considerable carbon emissions. As a result, adoption of CA over conventional tillage can result in significant reductions in carbon emissions (30–35 kg ha^{-1}) along with soil fertility improvement (Lal 2004).

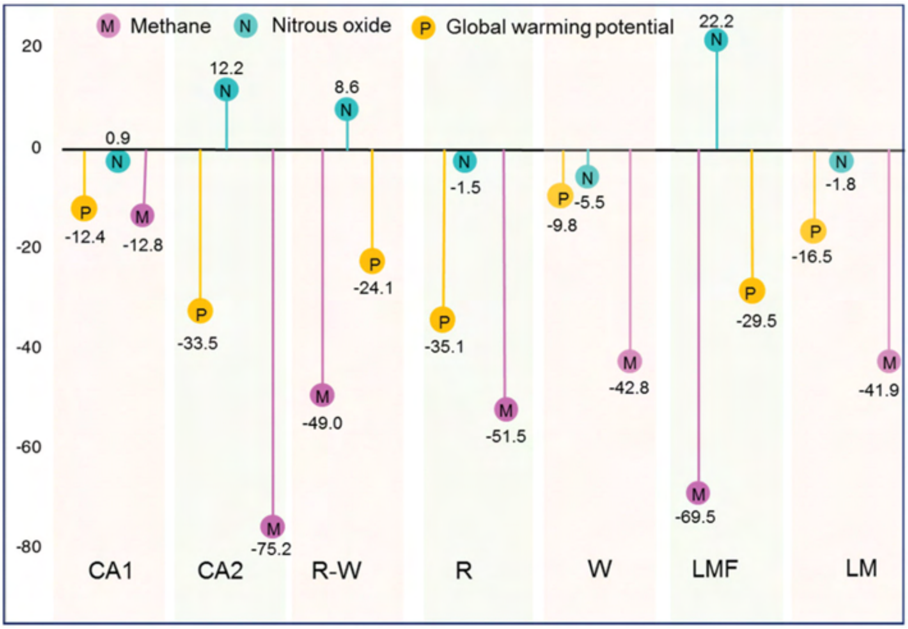


Figure 2. Relative emissions of methane, nitrous oxide and global warming potential in conservation agriculture (CA) as compared to conventional practices. CA1: Zero-tilled (ZT) direct seeding in either crop in a system; CA_2: ZT direct seeding in both crops in a system; R-W: rice-wheat cropping system; R: rice; W: wheat; LMF: moderately loamy fine soil; LM: medium loamy soil (source: Somasundaram et al. 2020)

The meta analysis of the data compiled by Somasundaram et al. (2020) showed methane and nitrous oxide emissions and GWP of different CA practices (Fig. 2). The maximum reduction is in GWP was noticed in Rice alone followed by CA2. While comparing the GHGs emissions from CA and CT practices, Jat et al. (2020) revealed CH4 emission reduction by 12.8% in CA1 (ZT direct seeding in either crop in a system) and 75.2% in CA2 (ZT direct seeding in both crops in a system) than CT. In rice and wheat, there were no significant differences in N_2O reductions whereas soil texture significantly affected as higher CH_4 reduction (69.5%) was recorded in moderately loamy fine soil than medium loamy soil (41.9%).

Adoption of conservation measures like zero tilled wheat with dry direct seeding of rice under rice-wheat system of IGP could bring down the GWP to half of conventional practices without compromising yields (Gupta et al. 2016). Haque et al. (2016) have developed a technique for transplanting of rice seedlings under non-puddled conditions which involves performing strip tillage on dry soil followed by 18-24 h of soil saturation to soften the soil in the strip and thus ease the transplanting of seedlings into the non-puddled strip. This practice caused a 29% reduction in CO_2eq emissions (Alam et al. 2019; Bell et al. 2019). CO_2 emissions are greatly reduced under CA owing to slower rate of organic carbon decomposition, which prevents CO_2 from being released from the soil (West and Marland, 2002; La Scala et al. 2008). Similarly, under CA practice, there is decreased CH_4 emission because of enhanced activity of methanotrophic bacteria, that accelerates CH_4 oxidation, and thus reduces CH_4 emissions (Feng et al. 2018; Mangalassery et al. 2014). However, increasing emissions of N_2O may be a problem when CA techniques are used instead of traditional tillage. N_2O emission is strongly determined by soil moisture (Ball, 2013), compact soil structure and greater soil moisture in CA might trigger N_2O emission. On the contrary, several studies have found that no-tillage system emits less N_2O over traditional one (Parihar et al. 2018). In another study of east Gangetic plain, revealed that minimum soil disturbance during the time of crop establishment for both upland crops and lowland paddy has yielded 50-63% of lower net life cycle GHG as compared to conventional puddled rice (Alam et al. 2019).

Fine textured soils have been proven to be superior for carbon sequestration because they give better physical and chemical protection to soil carbon by forming strong bonds (Jobbagy and Jackson, 2000; Six et al. 2002). In CA-based management approaches, significant water availability is pivotal to expedite the carbon sequestration process. Sufficient moisture is a prerequisite for root development and microbial activity thus it influences the breakdown of organic matter (Curtin et al. 2000; Lai et al. 2013). Moreover, proper management of nitrogen fertilizer is often needed to boost the crop yields in CA which also helps to increase carbon storage (Dalal et al. 2011). Similarly, balanced fertilization and application of FYM encourages carbon sequestration (Manna et al. (2005).

A meta-analysis results showed that when compared to conventional tillage, the carbon sequestration capacity of CA techniques was shown to be considerably higher (+16.30 percent) (Fig. 2.). CA based management practices under both aerobic and anaerobic scenario of soil conditions, resulted in significant reductions in CO_2 (-4.28%) and CH_4 (-25.67%) emissions and 7.87 percent reduction in global warming potential. Nonetheless, in aerobic circumstances, N_2O–N emission was lower in CA (-1.78 percent), but it was higher (+12.15 percent) under anaerobic soils in south Asian region (Kumara et al. 2020). Legume based farming systems were found to have greater potential of carbon sequestration than rice-wheat based cropping systems because of the nature of the legumes for supplying considerable amount of organic carbon to soils in long-term rice-wheat cropping system operative in CSSRI, Karnal, Haryana, India (Bharadwaj et al. 2019, Hazra et al. 2020).

The agriculture in South Asia is especially vulnerable to the climate change (Chattaraj et al. 2014), thus making it a global hotspot for future climatic vulnerability (Jat et al. 2019). Climate change is projected to make CA techniques more resilient to weather-induced pressures, hence they are widely reinforced in south Asian nations (Jat et al. 2012; Bhattacharyya et al. 2018).

2.2 Residue incorporation

The removal of residue resulted in a decline in carbon content in soil (Chowdhury et al. 2015). Contrary, retention of residue combined with no soil disturbances provides C input, reduces soil erosion, and protects soil aggregates, resulting in a rise in SOC level over time (Dalal et al. 2011; Page et al. 2019). The volume of crop residue returned to the soil, determines the extent of carbon sequestration in soil (Campbell et al. 2001). On the contrary, in cereal cropping system crop residue retention under no-tillage (Page et al. 2013; Ghimire et al. 2017) or sugarcane did not not result in a consistent rise in SOC (Page et al. 2013). Kraus et al.(2016) observed that incorporation of crop residue @ 2.8–3.4 t C ha^{-1} yr^{-1} in rice field after harvest is required to achieve stable SOC stocks under mixed upland crop–rice based systems. Previous research has also backed up the idea that soil cover has a positive impact on carbon sequestration (Curtin et al. 2000; Mafongoya et al. 2000). Further, several studies have found that adding/retaining agricultural residue had lesser effect on extent of carbon sequestration (Dexter et al. 1999; Reicosky et al. 2002; Ghimire et al. 2012). Humified rice straw plots had lower levels of CH_4 emission than other organic products, including green manure, farmyard manure and rice straw. It was reported that seasonal cumulative CH_4 emission could be reduced by incorporation of burned straw into the field (Khosa et al. 2012; Hoang et al. 2019). On the contrary some researchers reported that straw and green manure could augment methanogen population thus increased methane production (Zhou et al. 2020).

Rice residues were considered as an organic material of low-quality because they possess high carbon (36.7-42.3%), low nitrogen (0.47-0.85%) and lignin content (1.9–4.5%). It decomposes quickly in soils with adequate moisture, contributes to CO_2 evolution (Samahadthai et al. 2010; Puttaso et al. 2011), and serves as a substrate for production of methane (Samahadthaiet al. 2010). et al.In a study from China, it was found that incorporation of straw boosted annual SOC sequestration in the topsoil by 0.24–0.43 t C ha^{-1} yr^{-1}. However, it also increased the annual emissions of CH_4-C and N_2O-N, by 44–138 and 1.49 kg ha^{-1} yr^{-1}, respectively (Yuan et al. 2014). The incorporation of wheat residue (WR) and both wheat and rice residue

(WR + RR) enhanced the annual emissions of CH_4 by 38% and 61%, respectively, as compared to the rice residue (RR). The annual N_2O emissions were observed to be lower in RR and WR treatment over WR + RR treatment. Additionally, annual net GWP and greenhouse gas intensity (GHGI) were equivalent in the control and RR and quite lower in these treatments than in WR and WR + RR treatments (Wang et al. 2019). Liu et al. (2014) projected that total clearance of wheat stubble would raise CO_2 emissions by 3.90 ± 1.23 Mt yr^{-1} due to depletion of soil organic carbon in a spatial modelling study of residue integration in wheat-growing districts of New South Wales. The sequestered C 3.29 ± 1.11 CO_2 Mt $year^{-1}$, on the other hand, might be eradicated if 100% of the residue is kept.In the rice ecosystem, anaerobic decomposition of crop residue provides readily available carbon substrates for methanogens; additionally, organic matter acts as an electron donor, lowering the soil redox potential, encouraging methanogen activity and producing a large flux of CH_4 from rice paddy systems (Ma et al. 2009). However, the NPK plus practises of straw returning (NPK + SR) lowered net GWP and GHGI by 30.8% and 36.8%,respectively. The NPK + SR might be the optimum technique for mitigation of net GWP and thus enhanced grain yield and NUE in the existing rice-wheat cropping system, with the highest C sequestration and lowest GHGI (Guo et al. 2021). Previous researches suggested that incorporating rice straw rather than burning it could be a viable option if the temporary nitrogen immobilisation was offset by additional nitrogen application or the use of a microbial consortium.But this additional urea resulted in higher N_2O emissions, whereas inoculation with microbes performed better than straw+ FYM (Pathak et al. 2006). When compared to retention and incorporation residues of rice in a rice-wheat system, burning rice straw resulted in fewer N_2O emissions during wheat. Higher levels of accessible organic carbon resulted in increased microbial activity, improved nitrification and denitrification (in microsites), in the former two led to higher N_2O emissions, However, the authors' expectation was that burning would emit a significant amount of N_2O during the burning process, offsetting increased N_2O emissions due to straw incorporation (Pathak et al. 2006).

2.3 Integrated nutrient management

Organic material application have long been considered as a viable technique for carbon sequestration, soil fertility improvement, and for enhancing crop productivity (Guan et al. 2020; Liu et al. 2021). However, organic fertilization in soil was often reported to increase GHGs emissions. Alongside, inclusion of organics into farming practices has been highly debated around the question, can soil carbon storage compensate for rising GHG emissions(Lee et al. 2020)?

An integrated nutrient management (INM) practice was adopted in rice growing east gangetic plains of Bangladesh with less water, less nitrogen fertilizer, application of manure and residue management. This resulted removal of CO_2-eq emission of 2.43 t ha^{-1} $year^{-1}$, reduction of yield-scaled emissions from 0.55 to 0.65 t CO_2-eq t^{-1} yield and increase SOC level by 1.7% every year (Begam et al. 2018).

In another study, with a ten-year rice–rice cropping cycle, positive (128 kg $ha^{-1}yr^{-1}$) C sequestration was seen in INM practice compared to baseline soil C levels, while negative values were observed in control and balanced chemical fertilizer treatments (Naher et al. 2019). High rates of organics enrich soil carbon pools, which interact with soil particles to form resistant compounds and aids in C sequestration (Suwannarit 2008). Rate of manuring is a key parameter for controlling the emission of methane, with higher dose generally associated with higher CH_4 production (Sampanpanish 2012). Furthermore, dissolve organic carbon (DOC) and CO_2 emission from soil displays a positive relation. DOC also presumably boost CH_4 synthesis by supplying energy to methanogens (Zhou et al. 2020). Combined application of several organic sources could help in improving carbon storage. Researchers found that adopting (*Sesbanea* + FYM + vermicompost) treatment elucidated the highest build-up of soil organic carbon stock with increased C sequestration rate (Pradhan et al. 2015, Akhilesh and Nandan 2016). More SOC was recorded when chemical fertilizers were coupled with organic manure compared to fertilizer alone (Pathak et al. 2011). Similarly, FYM treatment with or without fertilizers enhanced SOC to unfertilized soil (Moharana et al. 2012). Application of azolla compost along with chemical fertilizers had increased productivity, soil carbon accumulation (16.9 g kg^{-1}), carbon storage (28.1 Mg ha^{-1}) and carbon efficiency ratio (16.9) but elevated CH_4 emission by 15.66% (Adhya et al. 2000). In a rice-wheat system, combining inorganic fertilizers with diverse organic manures improved soil aggregation which led to higher carbon sequestration due to physically protected carbon inside the aggregates in alluvial soils of West Bengal (Singh et al. 2009). The treatment straw addition (NPK+SR) had the highest cumulative CO_2 emissions. Seasonal CH_4 emissions in rice increased by 19, 23, 41, and 60% under coated controlled release fertilizer (CRF), NPK, pig manure (NPK+PM), NPK+SR, respectively, compared to PK. Moreover, compared with NPK, the cumulative N_2O emission during wheat increased by 4% under NPK+PM, but reduced by 100 and 39%in NPK+SR and CRF, respectively. NPK+SR recorded least net GWP (4.09 t CO_2eq ha^{-1}), while highest net GWP in NPK+PM @ 6.01 t CO_2eq ha^{-1}, due to relatively high CH_4 and N_2O emissions (Guo et al. 2021).

Over the course of 24 years of cultivation in a rice-rice cropping system, 27, 48 and 54% of the carbon supplied through farmyard manure (FYM), green manure (GM) and GM + FYM, respectively, was sequestered into the total organic carbon pool (Anantha et al. 2020). Integrated Plant Nutrition System (IPNS) based fertilization with cow dung (CD), poultry manure (PM), and vermicompost (VC) produced considerably more total CH_4, N_2O and CO_2 emissions than chemical fertilizer alone. However, with CD (52–54 kg C ha^{-1}), PM (62–64 kg C ha^{-1}), and VC (53–56 kg C ha^{-1}), the net ecosystem C budget found to be positive, but with chemical fertilization (-7 to -8 kg C ha^{-1}), it was negative (Hauque et al. 2020). In rice-wheat cropping system of the Indo-Gangetic Plain (IGP), substituting 25 and 100 percent N with organic sources increased CH_4 emission by 28 and 60% and GWP by 9% and 28% over chemical N treatment. However, application of *Sesbania* green manure (GM) with NPK considerably increased C sequestration. Overall, the C efficiency ratio (i.e. the units of C fixed in grain to units of equivalent C emission) was at par with the chemical fertilizer treatment. So, researchers recommended the adoption of GM in order to improve soil fertility without any adverse impact on the environment (Bhatia et al. 2005). It was reported from estern India that annual cumulative GHG emissions were higher in NPK+FYM over either NPK or FYM sole treatment applied to alluvial soils of Cuttack (Bhattacharya et al. 2013).

2.4 Fertilizer management

Providing optimum fertilizer and specifically nitrogen is very important to increase the crop productivity and biomass yield. After 22 years fertilization period (1991-2013) in south-western China under rice-wheat cropping system, authors reported that the treatments N, PK, NK, NP and NPK led to increase in SOC stock of top 20 cm of soil surface from 1991 level, however, in control SOC stock declined from the initial level. Among the treatments, highest SOC build up was recorded with NP and NPK with C sequestration efficiency [(SOC_{2013} – SOC_{1991})/C input *100] 17 and 14.4%, respectively (Zhao, 2016). Similarly, after 44 years of cultivation (1972-2016) with a Jute-rice-wheat cropping system in IGP, total SOC declined from the initial value of 18.17 to 16.54 Mg ha^{-1} in control and slightly increased to 18.77 Mg ha^{-1} in 100% NPK (total 300 kg N, 65 kg P and 150 kg K in a cropping year) (Singh et al. 2019). However, increasing fertilizer dose could lead to greater GHG emission. For example, Bhattacharya et al. (2012) observed that applying 60 kg ha^{-1} urea to rice has registered an increase of 1.31, 1.33 and 4.35 times increase in CO_2, CH_4 and N_2O emission over the control treatment and these emissions will further increased on addition of rice straw and green manure. However, the carbon efficiency ratio (grain yield in terms of carbon *GWP*12/44) of urea treatment was slightly higher (1.0) than control (0.95). In another study, different models were used to foresee potential SOC sequestration capacity (2100 A.D.), and it was discovered that in most areas of northern China, these soils will be a net source of CO_2. The extra carbon input from higher plant residues could not satisfy the loss of SOC in the north-west China when fertilizers were given. But manure or straw application can increase carbon sequestration, however, straw seems to be more prospective choice in the future (Jiang et al. 2019). Similarly, in an Inceptisol from Odisha, eastern India with a long-term rice-rice cropping system 39 years of cultivation history, total GWP followed the sequence NPK> N> control in bothwet and dry season rice. However, CER was similar in wet rice for these three treatments but in dry season rice, NPK showed significantly higher CER over control and N (Bhattacharya et al. 2013).

For subtropical rice-winter wheat cropping system of China, scientists advocated that the conventional practice of applying 250 kg N ha^{-1} could be reduced to 150 kg ha^{-1} without any significant decline in yield. This could help in reducing CO_2 and N_2O emission and also brought down the emission factor for N_2O from 0.76% to 0.53%. However, they reported CH_4 emission was negatively correlated with N dose and CH_4 emission followed: no N fertilizer> 150 kg N ha^{-1} > 250 kg N ha^{-1} (Yao et al. 2013). Greenhouse gas emissions were measured under four doses of nitrogen fertilizer (0, 60, 150 and 250 kg ha^{-1}). Researchers found that the cumulative emissions of GHG and the addition of N fertilizer having positive correlation to each other, and the largest emission was detected at 250 kg N ha^{-1}. GWP under the 250 kg ha^{-1} treatment was around 1.5 times more than no N fertilization (Tang et al. 2018). All these studies indicate that higher nitrogen fertilizer entailsthe risk of high N_2O emission. The process of denitrification releases N_2O as a gaseous intermediate in the reaction sequence which is also a by-product of nitrification. Among the various strategies to check N_2O emission, nitrification inhibitors (NIs) seem a promising option. NIs block the activity of ammonia monooxygenase (AMO), the enzyme responsible for converting NH_4^+ to NH_2OH and maintains the NH_4^+ in soil for a considerable period (Misselbrook et al. 2014; Ruser and Schulz, 2015; Gilsanz et al. 2016) which could be utilized by plants or fixed by soil clays.Several studies reported that use of NIs e.g.,neem oil andneem cake (Malla et al. 2005), 3,4- dimethyl pyrazole succinic acid (DMPSA) (Huerfano et al. 2016) with urea or ammonium-based fertilizers is an effective strategy to curb emissions of NO_x without reducing yield. One of the study scrutinized five nitrification inhibitors in rice-wheat cropping system of IGP. Both thiosulphate and Ca-carbide coated urea were proved as most effective for reducing N_2O emission under rice ecology, whilst, dicyanamide and thiosulphate were found most promising in wheat (Malla et al. 2005).

2.5 Direct seeded rice

The transplanting technique for establishment of rice is widely used throughout Asia. It entails soil puddling, which increases soil water retention, control of weed, and the availability of several nutrients (Haque et al. 2016), but destroys the soil structure completely. It was observed that the minimum tillage practice for other crops had no benefits if we continue soil puddling for rice transplanting. In this scenario, direct seeding of rice (DSR) with minimal tillage might be a feasible alternative for reducing GHG emissions and crop water requirements while increasing carbon sequestration, soil organic-matter turnover, nutrient relations and ensuring the timely planting of wheat in the rice-wheat system (Ahmad et al. 2009; Farooq et al. 2011). Consequently, some Southeast Asian countries have lately experienced a shift from conventional to DSR farming (Pandey and Velasco 2002). However, DSR has the danger of severe weed infestation, bird damage, low output owing to intermittent, unpredictable rainfall or insecure supply of irrigation water, and a high consumption of irrigation water during the seedling stage (Singh et al. 2011; Farooq et al. 2011). Sowing in DSR can be achieved in one of any three ways: dry seeding (sowing in dry soil), wet seeding (sowing pre-germinated seeds on wet puddled soils) and water seeding (sowing into standing water) (Farooq et al. 2011).

In a study undertaken in the rice-growing region of Karnataka, overall GHG emissions in the DSR were just one-seventh of those in the conventional system. Additionally, the DSR technique yielded a greater carbon efficiency ratio and carbon sustainability score (Basavalingaiah 2020). Another study in the subtropical China, reveals that direct seeded rice under no-tillage (NT) had 32 and 47% greater N_2O emissions and 29 and 52% higher NH_3 volatilization than conventional tillage (CT) in two consecutive rice seasons. Higher soil organic C and denitrification in NT accounts for increased N_2O emissions in NT (Jian-She, 2011). In India, several studies were undertaken using ‘InfoRCT’ model for rice-wheat belt of Haryana and Punjab. In Haryana, four distinct technologies namely transplanted rice, conventionally tilled wheat, DSR, and zero tilled wheat with residue retention, were investigated. Direct seeded rice + zero tilled wheat along with retention of residue had the lowest GHG emissions, emitting half as much as the traditional approach (transplanted rice + conventionally tilled wheat) (Mittal et al. 2018). Similarly in Punjab, GWP in transplanted rice varied from 2.0 to 4.6 t CO_2 eq. ha^{-1}, whereas DSR from 1.3 to 2.9 t CO_2 eq. ha^{-1}. According to the authors the total GWP could be decreased by 33 per cent if the entire area under transplanted rice in the state will be replaced by DSR (Pathak et al. 2013). A different study, involving DSR system of eastern India has shown that zero tillage yields lower N_2O, CH_4 and CO_2 emission than conventional tillage. Furthermore, application of nitrogen in four equal splits emitted less N_2O than neem coated urea, nitrogen management through SPAD, neem coated urea (75% N) + vermicompost (25% N) (Choudhury et al. 2019). However,contrasting findings were reported in a Chinese study, where wet DSR system yielded 25 percent more cumulative CH_4 emissions than conventional transplanting system. Moreover, during the flooding periods in DSR, most of the CH_4 emission occurred (Li et al. 2019). Scientists explained that a dry DSR for the entire rice growing period without submergence preserves aerobic conditions and prevents CH_4 generation. This is often prevalent in Asian rainfed highland ecosystems (Kumar and Ladha 2011; Sandhu and Kumar 2016). Wet DSR under continuous flooding, which is common in many irrigated regions, on the other hand, frequently causes greater anaerobic conditions that favour increased CH_4 generation in irrigated agroecology (Kumar and Ladha 2011).

2.6 Agroforestry system

In both industrialised and developing countries, agroforestry practises are promoted as a sustainable land use management approach. The agroforestry system has huge potential for carbon sequestration as predicted by IPCC compared to other management strategies (Fig. 3). Carbon is found in five main pools in agro-forestry systems: above ground biomass, plant roots, litter, microbiological, and soil C. The presence of trees would certainly increase the C sequestration per unit of land area due to sequestration of C by tree itself, buildup of more and more soil organic matter due to residue addition by trees than herbaceous crops, due to the fact that trees could explore more soils both horizontally and vertically to greater depths (Moreno et al. 2005). Agro-forest strategies like riparian and upland buffers, wind breaks, alley cropping, silvi-pasture, forest farming and agri-silviculture with site specific adaptive character provide a significant amount of environmental stability and climate change buffer (Bangroo et al. 2013). Considering the agroforestry as a potential GHG reduction method under the Kyoto Protocol, poor countries have been more interested in the potential of carbon sequestration by agroforestry systems (Albrecht and Kandji, 2003). The sale of the sequestered carbon through agroforestry could be a lucrative business opportunity for the subsistence farmers in poor nations, who are the primary agroforestry practitioners, as well as a benefit to the global society at large (Pakhom et al. 2020).

Rice cultivation has been largely discovered to be a major source of GHGs, owing to CO_2 emissions associated with strong crop root respiration stimulation. The SOC dynamics of agroforestry with cocoa forest and rice farming were compared, and it was discovered that the agroforestry system acts as a carbon sink with a positive OC budget (3.6 kg ha^{-1}) and a considerable contribution of OC was from necromass (Valenzuela-Balcázar et al. 2022). Similarly, in a mango-rice agroforestry system with 100 mango trees per hectare reported 1.94 Mg ha^{-1} carbon sequestration, accounting for 62 percent of total sequestration (Sureshbhai et al. 2017).

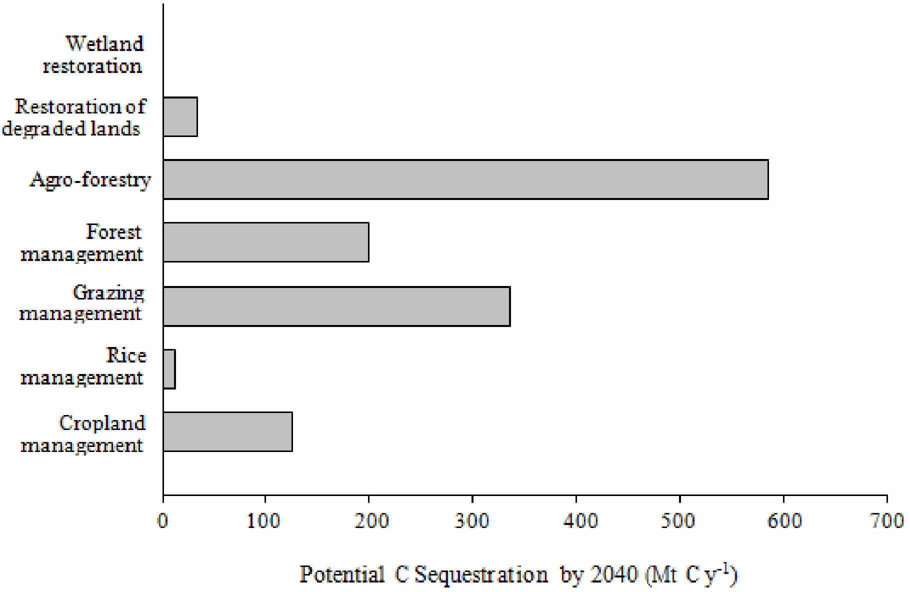


Figure 3. Carbon sequestration potential of different land use and management options (adapted from IPCC, 2000)

A study from Madagascar's Highlands measured the soil C content generated from three key tree species employed in rainfed rice-based agroforestry: *Eucalyptus robusta, Coffea arabica, and Citrus clementina.* With an average of 148 g C m^{-2} yr^{-1} after planting, *E. robusta* was the species with the highest tree-derived C values. *C. clementina*, on the other hand, only transmitted 12 g C m^{-2} to the soil. There was no evidence that *C. arabica* contributed much to the soil C stock. Moreover, rice biomass greatly differed depending on the number and type of trees present. Coffee and citrus enhanced rice shoot biomass compared to solo rice, while eucalyptus had no effect on shoot yield. However, rice root biomass was not affected by any agroforestry treatment (Rasoarinaivo et al. 2022). The researchers tested nine agricultural methods for carbon sequestration potential in Bangladesh's Dinajpur district, four of which were rice-based.Tree carbon sequestration was 6.26, 41.7, 128, 139 Mg ha^{-1} for mango (*Mangifera indica*), mahogany (*Swietenia mahogany*), lombu, and lombu + mango, respectively, in this rice-based agro-forestry (Pakhom et al. 2020). The highest annual carbon storage potential (97.900±8.090 t ha^{-1}year^{-1}) was recorded from Tripura that in annual crop components (i.e., *Colocasia*) followed by trees and its underlaid soil (4.250±0.340 t ha^{-1}year^{-1}) and lowest for bamboos (1.610± 0. 200 t ha^{-1} year^{-1}) (Sarkar et al. 2021). Moreover, total carbon loss from harvesting of this system was 78.768±7.128 t ha^{-1} year^{-1}. The study, therefore, recommends this agroforestry system for other waterlogged ecosystems at regional and/or global scale under a warm per-humid climate for both livelihood opportunities and environmental sustainability. Agroforestry has to play an important role in reducing vulnerability, increasing resilience of farming systems and buffering households against climate-related risks in the Himalayas. The net annual carbon sequestration rates for fast-growing but short rotation agroforestry crops such as poplar and Eucalyptus in Indian Himalayas have been reported to be 8 Mg C/ha/year and 6 Mg C/ha/year, respectively (Kaul et al. 2010).

2.7 Crop rotation

Crop rotation primarily affects the active pool SOC and its fixation and mineralization process (Hao 2002). For enriching the SOC, the crops in rotation should have high biomass producing capacity and higher carbon content. The pattern of crop rotation also plays an important role in SOC fixation. More rotation time encourages more interaction in the underground ecosystem and increase carbon sequestration (Tang et al. 2019). High density planting and crop rotation boost quality and quantity of crop residues and helps in increasing the SOC than solo cropping. (Alvarez 2005; Tang et al. 2019). However, according to some authors the crop rotations and their effect on C sequestration is complex, but crop rotations elucidate addition of more C input through their residues and also more of root biomass which point towards C sequestration. Nevertheless, net greenhouse gas emissions due to the effect of crop rotations is indistinct (Wang and Dalal 2015, Jayaraman and Dalal, 2021). A study was taken with Fallow-rice (RF), corn–rice (RC), rice–rice (RR) and sweet sorghum–rice (RS) systems in a sandy-loam soil of Thailand's Ratchaburi province. When compared to RR and RC RS rotations showed lower CH_4 emissions by 78–84% and non-CO_2 GHG emissions by 68–78% Further, soil carbon budgets recorded positive values in the RC and RR treatments.In the RR, RC, and RS treatments, SOC stock were maintained compared to RF treatment, where it declined (Cha-un et al. 2017). In another study on Yangtze River district of China, however rice–wheat rotations had the highest yields, C inputs, and biomass C, suggesting that they may outperform cotton–barley rotations and broad bean–maize in terms of soil productivity and SOC sequestration. However, because of decreased C inputs, mainly from the broad bean–maize rotation, SOC sequestration was lower than rice fields in comparable climatic condition (Wang et al. 2018).

Under varying tillage practices, converting a year-round flooded single rice system in China to a rice-rapeseed system reduced yearly CH_4 emissions by 40-70% while increasing N_2O emissions by 1.45-3.5 times. It also, resulted in decreased annual GWP and GHGI (i.e., GWP per unit grain yield) (Hao, 2016). In another study, out of nine different cover crop rice rotations (i.e., fallow, rape seed, clover, barley, wheat, garlic, fababean, lettuce and cabbage), clover-rice rotation was found to be the most environmentally friendly. It saved non-renewable energies (fuel, nitrogen etc.), improved rice productivity, lowers emission of CO_2 and GWP, showed the lowest freshwater eutrophication and ozone depletion (Morandini et al. 2020). Similarly, a long-term field experiment from India evaluated the impact of four distinct rice-based crop rotations (rice–wheat, rice–chickpea, rice–wheat–mungbean and rice–wheat–rice–chickpea). The water stable macroaggregates (WSMA) was found highest under rice–wheat–mungbean rotation (64.8%), followed by rice–chickpea (57.0%), rice–wheat–rice–chickpea (50.3%) and lowest under rice–wheat (49.9%) respectively. Incorporation of legumes in rotation enhanced the active carbon pool (9–18%), SOC (6–17%), and carbon management index (5–7%) compared to rice–wheat rotation and followed the same order as WSMA (Nath et al. 2019). Under various rotation schemes, in Shanghai rice paddy the total GHG emissions were different in terms of GWP, in the following order: rice-winter wheat system > rice-Chinese milk vetch system > single rice rotation system (Zhang et al. 2019). Separate study included rye and rapeseed in a rice-rice system and found an upsurge in annual GWP by 102.6 and 34.8%, respectively, while Milkvetch reduced it by 27.8%. The legume (milk-vetch) also reduced CH_4 flux by 16.3%, although rye and rapeseed increased CH_4 emission by 52-117%. The difference was mainly related to the former's low C/N ratio. High dissolved organic carbon in rye and rapeseed encouraged CH_4 emission which serves as a substrate for methanogens (Raheem et al. 2019).

2.8 Biochar

Biochar is charred organic matter which can sequester carbon and enhance soil characteristics (Lehmann and Rondon 2006). It has largecarbon (C) contents (Verheijen et al. 2009), high surface charge density (Zimmerman 2010); large surface area (Glaser et al. 2002) and long mean residence times (MRTs) (Singh et al. 2012). Myriad of studies are available on biochar and its effect on GHG emission (Liu et al. 2016, 2019). Qin et al. (2016) reported that application of biochar, might enhance methanotrophic microbes, increased soil pH in a 4-year field experiment under a paddy rice cropping system. As a result, biochar application @ (20 t ha^{-1}) reduced methane (CH_4) as well as gross GHG emissions. Furthermore, biochar applied @ 20 and 40 t ha^{-1} significantly decreased the CH_4 emissions by 29.7% and 15.6% respectively (Xiao et al. 2018). However, some of the prior studies reported that biochar might provide higher substrate in flooded paddies (Wang et al. 2012), so it did not reduce CH_4 emissions from rice field or even have enhanced it (Zhang et al. 2010; Wang et al. 2012 et al.). Liu et al. (2019) conducted a field experiment in rice-winter wheat rotation system of six-year durationwhere biochar was applied 0, 20 and 40 t ha^{-1} with and without N fertilization (150 kg ha^{-1}). Results revealed that biochar application led to diminished emission of N_2O from the rice paddies for the initial two seasons following only the single amendment and further high rate of biochar application reduced GHG emission from the fertile paddy soil. Biochar addition reduced CH_4 and N_2O emissions to the tune of 11.2–17.5% and 19.5–26.3%, respectively, with increase in yield by 7.9-9.2%, on average (Wu et al. 2019). This could be due to reduction in nitrite reductase nirS and nirK genes in the biochar treatment (Wu et al. 2019) and increase in nos Z gene indicates further reduction of N_2O to N_2 which curbed N_2O emission. A field experiment having six doses of rice husk derived biochar (RHB), ranging from 0.5 t ha^{-1} to 10.0 t ha^{-1} was conducted in India in which, variation in C mineralisation and different C fractions were studied. The results of this three year experimentation revealed that cumulative CO_2-C emission increased with increasing the rates of RHB. Biochar @ 10.0 t ha^{-1} registered maximum total organic C (3.26%) and a larger fraction of non-labile C (63.8%) as compared to other treatments indicating higher C sequestration (Munda et al. 2018). However, in a 4-years' field experiment under paddy rice cropping system, biochar application did not change SOC significantly (Xiao et al. 2018). Role of biochar's for supplementation of organic/inorganic nutrients and consequently boosting crop growth would be altered if some extractable OC components and water soluble nutrients were removed (Korai et al. 2018).

3. Conclusion

Choosing appropriate carbon and nitrogen management practices emerged as a key factor to sequester more carbon and regulate GHG emissions from rice-based cropping system. Right type of carbonaceous material in conjunction with judicious application of nitrogenous fertilizers can mitigate greenhouse gas emissions responsible for global climate change. Substitution of N with organic sources especially *Sesbanea* green manure in rice-based cropping system in general increased CH_4 emissions and GWP though it enhanced carbon sequestration and the carbon efficiency ratio was found to be at par with the chemical fertilizer treatment. The combined use of organic residues with varying biochemical composition could be a efficient carbon management strategy to increase carbon sequestration soil. The integrated application of balanced application of NPK along with straw emerged as the optimum magnagement option to mitigate net GWP and increase the grain yield and NUE in the existing rice-wheat cropping system, with highest C sequestration and lowest GHGI. However, Integrated plant nutrition system (IPNS) based fertilization with cow dung, vermicompost and poultry manure should be used cautiously as these organic sources produce considerably more total CH_4, N_2O and CO_2 emissions than chemical fertilizer alone. DSR is another emerging technology which not only proven to enhance carbon efficiency ratio and carbon sustainability score but also capable of emitting lesser amount of GHGs. Direct seeded rice + zero tilled wheat along with residue retention proved to be a potential technology having lowest GHG emissions, emitting half as much as the traditional approach. Adoption of appropriate crop rotation e.g. sweet sorghum-rice drastically reduced CH_4 emissions and non-CO_2 GHG emissions as compared to rice–rice and corn–rice cropping sequence. Carbon credit to the subsistence practioners of agroforestry mainly in poor agro-ecologies of the world could serve very beneficial not only for their livelihood but also to promote and adopt the C sink strategy for a better future. Application of biochar emerged as a win win strategy not only for carbon sequestration but also for reduction of GHG emissions from rice-based crpping systems. However, some contradictory reports are also available stating no reductions on GHGs emissions. The economically viable and socially acceptable technologies need to be popularized among the rice growers as mitigation options with the consolidated initiative of the government and other organizations.

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Chapter 16

Advanced Techniques for Precision Farming in Rice

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Abstract

The growing demand of rice has to be met by increasing production with less resources *viz*. land, water and manpower; and by optimizing usage of all agricultural inputs for which precise management of inputs are considered very important. Precision Farming (PF) assists in identifying, analysing, and managing the spatial and temporal variability of different parameters such as soil, water and nutrients thereby avoiding negative impact on environment due to imbalanced use. Precision rice farming is implemented using precision farming tools such as remote sensing, Global Positioning System (GPS), Geographical Information System (GIS), site specific nutrient management systems, variable rate applicator, models, and decision support systems. Precision farming technologies can help to achieve targeted rice production by using them in field preparation, weed management, irrigation water management, fertiliser application, insect and pest control, crop harvest, and post-harvest operations. This chapter discusses about various precision farming technologies used in rice farming along with strategies for large scale adoption.

Keywords: rice, precision farming, nutrient management, water management, weed management, pest and disease management

1. Introduction

Rice is a staple food for more than half of the world's population, including more than 65 percent of Indians. India has the world largest rice area and is the second largest producer. It is produced on an area of 43 m ha under various climatic and soil conditions in distinct ecologies, accounting for more than 40% of total food grain output and playing an important role in people's food and livelihood security. Rice plays a major role in India's diet, economy, employment, culture and history. The crop is grown all-round the year in one or more parts of the country.The production and productivity of rice is on increasing trend mainly because of increased use of various inputs, such as fertilizers, irrigation water, plant protection chemicals, use of machinery, electricity in rice production in past few decades. But during the recent decade, there is a decline or stagnation in rice productivity due to imbalanced nutrient use affecting the soil health. Unsustainable use of natural resources and imbalanced fertilizer application has resulted in many environmental and economic problems like greenhouse gas emission, water bodies pollution and increased cost of cultivation (Pathak et al. 2018). The growing demand of rice has to be met by increasing production with less resources viz. land, water and manpower; and by optimizing usage of all agricultural inputs for which precise management of inputs are considered very important. Precision farming technologies can play a big role in achieving the targeted production of rice through its applications in field preparation, weed management, irrigation water management, fertilizer application, insect and pest control, crop harvest and post-harvest operations. Precision farming also ensures the most efficient use of resources, making rice cultivation less energy-intensive, environmentally friendly, and highly productive.

Precision farming is site specific management of any agricultural problem for a specific area rather than applying fertilisers, pesticides, and herbicides uniformly across the field. Precision agriculture is defined as "an information and technology-based management system that is site specific and uses one or more of the following data sources: soils, crops, nutrients, pests, moisture, or yield, for optimum profitability, sustainability, and environmental protection (McLoud, 2007). "Precision Farming (PF) assists in identifying, analysing, and managing the spatial and temporal variability of different parameters such as soil, water, nutrients, and so on within the field, as well as in timely application of inputs in required amounts to ensure sustainability with minimal negative impact on the environment." Precision Farming is based on technologies such as global positioning system (GPS), remote sensing (RS), decision support system (DSS) and variable rate technology (VRT) etc (Mondal and Basu 2009).

2. Status of precision farming technologies across the world

Precision farming started to be practiced in field in the early 1980s in the United States. The "Soil Doctor" sensor, designed in 1982 was used without GPS to vary nitrogen application, pioneered on-the-go soil sensing to guide fertilizer use (Colburn, 1999; Lowenberg-DeBoer, 2004). Long before the concept of PF, optical sensors were developed to diagnose plant conditions based on reflectance (Markwell et al., 1995). In 1983, US government allowed global positioning systems (GPS) for civilian use. Soil scientists and agribusiness researchers in the United States and Europe began developing equipment and methods for variable rate fertiliser application in the 1980s (Haneklaus and Schnug, 2002; Mulla and Khosla, 2016). In 1985, University of Minnesota researchers experimented in crop fields with various lime inputs. Grid sampling was also becoming popular at the time (applying a fixed grid of one sample per hectare). The first input recommendation maps for fertilisers and pH corrections were created using this technique at the end of the 1980s. Since then, the usage of yield sensors produced from new technologies, as well as the advent of GPS receivers, has gained popularity. The first commercially successful grain yield monitors were introduced in 1992. Competing research teams in Europe and North America developed sensors that could guide nitrogen application in the mid-1990s. The Yara N-Sensor, Crop-Circle, and Green-seeker were among the first sensors to be commercialised in the late 1990s. It became possible to use sensor readings to create fertiliser and pesticide application maps, or to create on-the-go sensor-algorithm-application equipment, thanks to the Global Navigation Satellite System (GNSS). The equipment guidance of the Global Navigation Satellite Systems was commercialised in the late 1990s, first in Australia and then in North America. Farmers in the American Midwest (US) are attempting to maximise profits by varying the rate of fertiliser applied across the field based on the soil type. Precision agriculture evolved at varying rates around the world. The United States, Canada, and Australia were the forerunners. In terms of PA practise, the United States and Australia are the two most leading countries (Warren and Metternicht 2005). The United Kingdom was the first country in Europe to follow this path, closely followed by France in 1997-1998. Argentina, where it was first introduced in the mid-1990s, is the leading country in Latin America. The development of GPS and variable-rate spreading techniques aided in the establishment of precision farming management practises. The technologies used to collect remote sensing data evolved throughout the twentieth century, from visual observations of airborne individuals to plane cameras, high-resolution satellites, and digital sensors mounted in unmanned aerial vehicles (Mulla, 2013). In the early years of the twenty-first century, unmanned aircraft were used for crop monitoring on a trial basis. In rice cultivation, many precision agriculture technologies are used across the world for reducing the input use, maximizing productivity and for environmental sustainability. Laser guided land levelling was found to be effective in saving water (Aryal et al. 2015; Anantha et al. 2021). Site specific nutrient management has reduced nitrogen use and improved rice yield at various locations (Peng et al. 2010; Khurana et al. 2007; Chivenge et al. 2021). Nitrogen management based on precision farming tools like leaf color chart, green seeker and SPAD meter improved nitrogen use efficiency in rice (Yao e al. 2012). Using crop canopy sensors, many studies have been conducted to estimate rice growth and N status (Nguyen et al. 2006; Stroppiana et al. 2009). Precision water management technologies such as reducing ponded water depth to soil saturation or alternate wetting and drying (AWD) irrigation technologies that can save 15-50 percent of water input improved rice water use efficiency (Bouman et al. 2007).

3. Status of precision farming in India

With nearly 17% of the world's population, India confronts the issue of meeting the demand for agricultural goods from this ever-growing population. In order to establish eco-friendly solutions for increasing crop productivity, it is critical to modernise traditional agricultural techniques and prepare for a technological revolution. Precision agriculture and other smart farming concepts may be used effectively to achieve this goal. Precision farming is still a new concept in Indian agriculture. A vast amount of data has been collected on a variety of aspects, including soil characteristics, climatic parameters, topographic features, crop requirements in terms of consumptive use, and nutritional requirements. The instruments required for recording these parameters are also available. There are numerous cases in which few precision farming components have been used to greater advantage in enhancing yields. The Working Groups (WGs) of the India–US Knowledge Initiative on Agriculture (KIA) have highlighted PF as one of the primary thrust areas. PF research is projected to play a major role in the recently formed ambitious agricultural research programme, which will focus on agricultural technology breakthroughs. Many ICAR institutes are working on using variable rate inputs in different crops and cropping systems. The role of remote sensing in mapping the variability in space and time is being investigated at Central Potato Research Station farm in Jalandhar in collaboration with the Space Application Centre (ISRO) in Ahmedabad. A precision farming resource centre was established with five demonstration farms at the JRD Tata Ecotechnology Centre of the MSSRF M.S. Swaminathan Research Foundation, Kannivadi, Tamil Nadu with the financial aid of National Bank for Agriculture and Rural Development (NABARD) to alleviate poverty through the use of PF technology. In addition, various low-cost GIS-based decision support systems and agricultural machinery are gaining popularity for use in precision farming. Tamil Nadu government reported an increase in yield by three to twelve times due to the use of precision agriculture techniques over conventional ones. Across the country, IT is being introduced into farming and information services are provided to farmers via SMS using mKisan portal. Farmers are also using mobile apps to get weather information and early warnings. Satellite based nitrogen fertiliser recommendation has been developed for rice using MODIS data (Tripathi et al., 2017). The Indian Council of Agricultural Research (ICAR) has initiated an ambitious programme on precision farming "Network Programme on Precision Agriculture" in which 18 ICAR Institutes are working together and ICAR-National Rice Research Institute is also a collaborative partner in this project. Various sensors and drone technology is being employed as well which has the capability of smooth scouting over farm areas, acquiring exact information, and communicating it in real time.

4. Precision farming in rice

Precision farming could help to achieve desired rice production by using proper technologies in field preparation, weed management, irrigation water management, fertiliser application, insect and pest control, crop harvest, and post-harvest operations.

4.1 Precision field operations

Precision in farm operations is critical for achieving the targeted rice production. Precision farming tools have the potential to improve rice mechanisation by improving precision, energy efficiency, and safety in farm operations through better field preparation, sowing and transplanting, nutrient management, weed management, pest and disease management, post-harvest, and final product quality.

Paddy fields prepared with optimal tillage guarantee that enough water depth in rice fields is maintained for a longer length of time, ensuring that all resources such as water, fertilisers, and pesticides are used more efficiently. Laser land levelling is frequently used for proper rice field levelling due to its numerous advantages. Rice cultivation using mechanised direct seeding is a cost-effective and efficient method that is gaining popularity among farmers, owing to labour shortages and rising rice production expenses. Precision seeders for sowing of rice crop are getting worldwide popularity due to their cost effectiveness and efficiency. Automated farming robots for direct seeding of rice, on the other hand, may be a viable option as they can control the number of rice seeds per dropping, maintain the spacing between the dropping points, and navigate the field automatically.

Manual transplanting is time-consuming and labour-intensive, making it a costly endeavour, but mechanical transplanters require less work and have a larger field capacity, allowing for easy and timely rice transplanting. Precision in transplanting in terms of depth of transplanting, spacing between hills, and spacing between rows can be accomplished with either manual or mechanised (walk type and riding type) transplanters. Mechanical transplanters improve field efficiency and eliminate drudgery. A variable row automated rice transplanter can be developed for highly precise transplanting operation by utilising a real-time kinematic global positioning system (RTKGPS) to find the position and fibre optic gyro (FOG) sensors to monitor the vehicle's direction and inclination. Many researchers have created and validated GPS guided transplanters using similar methodologies. Recently, an on-the-go soil sensor with a 6-row rice transplanter equipped with an ultrasonic sensor to correctly detect topsoil depth was developed and validated (Morimoto and Hayashi, 2017).

Quantification of seedlings is important to match the low seed rate of hybrid rice varieties as well as diverse methods of rice production such as system of rice intensification (SRI). To study the marginal signal count at various transplanting speeds, a seedling number counting equipment is equipped with a high-speed rice transplanter. The seedling counting device counts transplanted seedlings using signals and then shows the results on the board. To obtain synchronisation between the counter signal and the transplanting claws, an absolute rotary encoder was employed to establish the angle of the push point and the stop position of the transplanting claws. On a computer, a logic analyzer is utilised to convert the encoder signal into usable data. A rice transplanter can also be upgraded and outfitted with a ground-based integrated sensor and instrumentation system to monitor field conditions in real time (Singh and Sharma, 2017). This technology improves transplanter operating precision by tracing the prescribed route in straight, 90°curve, and arc directions. A navigational control system embedded in a path planning and preview control algorithm can be employed for this purpose. The use of robots and the automation of farm operations is essential for the future farming. Agricultural robots can only be successful if they work in constantly changing agricultural situations and produce work of comparable quality to current methods. Many studies have shown that agricultural robots are ideal for use in paddy fields.

4.2 Precision nutrient management in rice

The "Four R's" (right amount, right source, right location, and right time) are utilised to achieve effective and environmentally sustainable nutrient management (IFA, 2009). Precision nutrient management seeks to improve agricultural production systems' productivity, efficiency, and profitability through the use of modern, innovative, cutting-edge, site-specific technologies that regulate the spatial and temporal variability of soil inherent nutrient supply. Judicious nutrient management is critical in the production of any crop, including rice.

In developing countries, farmers prefer traditional method of fertilizer application in which they either overuse the fertilizers or apply them in less amount instead of recommended dose, which does not supply enough nutrients as required by the crop due to spatial variability of nutrient availability (Adhikari et al. 1999). The main cause of low fertiliser use efficiency in rice is improper fertiliser application timing and rates (Peng et al. 2010). Overuse of chemical fertilisers wastes money, degrades land, pollutes the environment, and lowers the yield response to the applied fertiliser (Yang et al. 2017). Excess N and P fertilisation causes environmental issues such as increased greenhouse gas emissions, eutrophication, and ground water contamination, and P fertilisers introduce heavy metals and radioactive pollutants into the soil-water-plant continuum (Fan et al. 2011). On the contrary, proper NPK fertiliser application can enhance rice output by 2-3 times (Mondal and Basu 2009). Precision nutrition application can aid in lowering production costs and increasing rice yield (Peng et al. 2006). Due to large seasonal K inputs via irrigation water and the release of non-exchangeable K, significant responses of rice to fertiliser K application are not observed in many rice growing areas (Forno et al. 1975). Hence, N management in rice has become more important, as N insufficiency in rice is the most common problem with a huge economic impact, and crop growth and grain yields are heavily reliant on the effective application of N fertiliser in the field.

One of the most important aspects of adopting precision nutrition management is obtaining real-time spatial crop N status within a field. Due to the significant cost and time involved, determining plant N concentration using remote sensing techniques is preferable to traditional destructive chemical analyses of plant samples. Commonly used methods for determining the correct amount and timing of N administration in rice include field diagnostic approaches based on leaf colour utilising a leaf colour chart (Nayak et al. 2013), leaf chlorophyll concentration transmittance using SPAD meter (Solari et al.2010), crop light reflectance using ground based remote sensors like Crop Circle™ and Green Seeker® etc. (Pateel et al. 2017), and use of GIS, RS and crop simulation modelling approaches. Crop production can be increased by assessing the spatial and temporal variability of soil parameters and applying site-specific fertilisers as needed.

4.2.1 Delineation of homogenous management zones

The spatial soil nutrient variability can be addressed by establishing homogenous management zones. Delineation of management zones can be accomplished by utilizing the information on crop yield, soil data and crop conditions by using modern tools such as remote sensing. The management zones can aid in site-specific nutrient management rather than uniform nutrient application throughout the field (Tripathi et al. 2015; Tripathi et al., 2019). Using computer-controlled equipment, management zone maps are utilised to apply varied rates of different inputs to distinct management zones within the field. The application of nutrients at variable rate based on variability/management zone maps is called as Variable Rate Technology (VRT).

4.2.2 Sensors for precision nutrient management

Fertilizers application should be based on crop requirement and spatial variation of nutrients. The determination of soil nutrient status aids in providing soil test-based fertilizer recommendation. However, traditional soil testing methods involving manual or mechanical soil sampling are time-consuming and expensive, making it difficult to characterise spatial or temporal variability of nutrients in soil. Therefore, fast, on-site and reliable measurement methods for assessing spatial and temporal soil variability of fertility related parameters with high sampling density like on- the-go real-time sensors (optical, radiometric and electrochemical sensors) prove to be immensely helpful for geographically referenced sampling and analysis at higher spatial resolution compared to conventional systems.

4.2.2.1 Wireless sensor network (WSN) for precision Nutrient management

WSNs are used to track the weather, soil nutrient levels, crop health, and agricultural product quality. Many sensors and radio frequency (RF) modules, along with processors, make up a wireless sensor network (WSN). Sensors after recording the data communicate wirelessly to a base station and send the data via a wireless communication link. Sensor nodes combine data from a variety of sensors, such as humidity, pressure, and temperature sensors, allowing these WSNs to process a wide range of data at the same time.Sensors today have incredible sensing, storage, processing, and communication capabilities. WSNs can be utilised as a cost-effective means of increasing agricultural productivity.

4.2.3 Site specific nutrient management

Site-specific nutrient management (SSNM) is required to improve food production while lowering costs and leaving a smaller environmental footprint (Goulding et al. 2008). Due to the inherent variability of soil nutrients, site specific nutrient management for more efficient use of resources and nutrients is the need of the hour. Site-specific nutrient management strategy in rice in Asia, specifically for N, has been demonstrated to be beneficial in increasing rice output by 11% and recovery efficiency by 31% to 40% on average (Dobermann et al. 2002).

Rice Crop Manager (RCM) for Odisha was created by the International Rice Research Institute (IRRI) in partnership with ICAR-National Rice Research Institute and Orissa University of Agriculture and Technology by undertaking various nutrient omission plot experiments across Odisha. RCM is a web-based tool that sends crop management recommendations to farmers via text messaging and the internet, based on their field and rice-growing conditions. RCM addresses various constraints that limit rice output and farmers' profits in addition to nutrients.

Table 1. Precision tools and techniques to assess plant nitrogen requirement

Type (Name) of the sensor/ Approaches	**Benefit over control/conventional method**	**Reference**
Proximal sensing		
Optical crop canopy sensor (Green Seeker, GS)	Reduced nitrogen application, improved recovery efficiency and agronomic use efficiency of nitrogen over blanket rate farmer practice	Bijay-Singh et al. 2015
Crop Circle (CC) active sensor (ACS-470)	Increased grain yield, agronomic NUE and partial factor productivity by 18%, 46% and 20% respectively over green seeker-based nitrogen management	Shi et al. 2015
FieldSpec_FR PRO spectro-radiometer	N estimation from field canopy hyperspectral data.	Wang et al. 2013
Chlorophyll meter	Reduced nitrogen requirement of rice from 12.5 to 25%	Bijay-Singh et al. 2002
Leaf Colour Chart (LCC)	Direct seeded (DSR) and transplanted rice (TPR) yields improved by 10.3-13.3 percent and 9.9-10.9 percent, respectively, over control. N recovery efficiency was enhanced by 10.7-12.4 % and 9.1-12.2 % in DSR and PTR, respectively.	Nayak et al. 2017; Mohanty et al. 2017

	Average saving in N was 25 kg/ha	Balasubramanian e al. 2002
	Fertilizer N saving was 50% compared to blanket application when LCC shade 4 was used as threshold value in wet DSR	Nachimuthu et al. (2007)
Remote sensing		
Low Altitude Remote Sensing (LARS) system using UAV	For estimation of N and chlorophyll content	Zhu et al. 2009
Satellite Remote Sensing	Predicting leaf N status in rice which helps in deciding supplemental N application requirements in rice.	Tripathi et al. 2017; Huang et al. 2013; Ranjan and Parida (2020)
Aerial imagery and site maps	remote-sensing based precision N applications in rice	Brinkhoff et al. 2021
	yield, N concentration, N uptake, biomass, and plant height of rice were estimated using aerial images	Stavrakoudis et al. 2019
Site specific nutrient management		
Site specific nutrient management (SSNM)	Over recommended practise, SSNM reduced nitrogen and phosphorus application by 4 and 28%, respectively, while demanding 80 percent more potassium and increasing grain yield by 6%.	Marahatta, 2018
Crop simulation models and Decision support systems		
CERES-Rice model	Using calibrated model the nitrogen requirement for attaining a particular rice yield can be estimated	Amiri et al. 2013
Nutrient Expert (NE)	Increased crop yield, reduced fertilizer consumption and associated greenhouse gas emission	Sapkota et al. 2021
Rice crop manager	Higher yield was observed with RCM over farmer's practice	Sharma et al. 2019

4.2.4. Remote sensing for precision nutrient management

In comparison to extensive sampling and lab analysis methods, remote sensing is a very good choice for determining the plant nutrients status. Using hyperspectral remote sensing data, Mahajan et al. (2017) found that N, P and S status in rice crop can be predicted at panicle initiation. They found that 670, 700, 730, 1090, 1260, and 1460 nm bands can be utilised to monitor N, P, and S nutrients. The accuracy of forecasting N status using NDVI was better, while P and S could not be predicted with greater accuracy using NDVI.

4.2.4.1Unmanned aircraft systems (UAS) for precision nutrient management

Due to low spatial resolution of satellite data products, satellite remote sensing data has not percolated to the farm level (Atzberger 2013). Other limitations include temporal resolution, cloud coverage during satellite passes, and data transfer delays to users.Unmanned aircraft systems (UAS), often known as remotely piloted aircraft, unmanned aerial vehicles, or drones, are an alternative to satellite remote sensing for farm scale applications.The UAS provides a platform with attached sensors that have a high spatial resolution data capture mechanism, and the time of data acquisition and coverage may be modified based on the user's preference and demand (Zhang, Walters, and Kovacs 2014). Drone captured images have spatial resolutions of up to centimetres, making it simple to monitor key biophysical parameters such as leaf nitrogen content, leaf area index (LAI), and plant biomass at critical growth stages of the crop (Warren and Metternicht 2005).

4.2.5. Precision application of fertilizers

Precision fertiliser application methods for rice currently available include deep placement of fertiliser as briquettes, which has been shown to be effective in reducing nutrient losses (NPK), surface runoff of N and P, and emissions of nitrous oxide and nitric oxide to the environment while also increasing rice yield (Chatterjee et al. 2018). Application of soluble fertilizers through drip irrigation (fertigation) reduces fertilizer lossesand increases the rice yield. Precise rate, optimum time, and precise fertiliser application methods resulted in fertiliser savings as well as increased crop output as compared to traditional nutrient management practises (Table 2). Improved NUE can also be accomplished by employing slow-release nitrogen fertilisers/stabilized nitrogen fertilisers, by reducing leaching and gaseous losses of nitrogen (Trenkel 2007).

Table 2: Precision nitrogen application techniques in rice

Application technique	**Benefits over conventional method**	**Reference**
Deep placement of urea briquettes	Enhanced yield, NUE and reduced N_2O emission	Nayak et al. 2017

Drip fertigation of NPK	Higher grain and straw yield was observed over soil application	Kombaliet al. 2017
Variable N application based on SPAD Chlorophyll meter readings	Reduced nitrogen requirement by 33.3% and improved agronomic use efficiency by 58%	Mainak Ghosh et al. 2020
varied fertilizer application based on management zones mapped using precision farming tools	Reduced fertilizer application, improved nutrient use efficiency and yield	Patil 2009; Tripathi et al. 2015

4.3. Precision water management

Irrigation water management is an integral part of precision rice farming. Under the predicted water scarcity scenario, finding innovative water saving technologies for improving rice water usage efficiency is extremely desirable (Kumar et al. 2019). The high water requirement is due to rice cultivation in lowland conditions, where seepage and percolation account for 50-80 percent of total field water outflow.The conventional practice of growing rice in continuously flooded condition for most of the crop growth periods is undesirable.Alternate Wetting and Drying (AWD), midseason flooding, drainage with intermittent irrigation, drip irrigation, tensiometer-based irrigation scheduling at fixed soil moisture tensions ranging from 0 to -40 kPa, and irrigation at 1–5 day intervals after standing water disappearance are some of the innovative irrigation management practises (Kumar et al. 2021). Water needs in field vary spatially due to soil characteristics. As a result, irrigation requirement of the same field may vary in different zones. Applying excess or less quantity of water than crop requirement will lead to crop stress there by affecting the yield. Precision water management is defined as site-specific water management, or the application of water to a specific site in the volume and at the time required for optimum crop production, profitability, or other management objectives at that specific site. Another critical factor for crop productivity is the quality of the water. As a result, precision water management is defined by both good water quality and adequate water supply. Precision irrigation management emerges as a potential solution for increasing irrigated agriculture productivity while reducing environmental impact. Besides micro irrigation and other automated irrigation technologies, the use of geographic information systems (GIS), global positioning systems (GPS), remote sensing (RS) and laser land levelling were primarily used to bring precision to the rice crop irrigation. Some of the visual observations for scheduling irrigation on AWD criteria are leaf rolling and appearance of hairline cracks on the soil surface (Singh et al. 2009; Saharawat et al. 2010). Under measured observations, the AWD is based on a fixed time interval, where irrigation scheduling is done after fixed periodic intervals during different growth stages (Arora et al. 2006). Field water tubes are installed in field for real time monitoring of the perched water table. The plastic tubes (length 30 cm, diameter 10 cm) are inserted into the soil to a depth of 15-20 cm. The soil water enters the tube through the perforations. Irrigation scheduling is done when the water level in the pipe reaches a pre fixed level.

For real time measurement of SWP, tensiometers are installed in the field. At similar SWP, the availability of water for plants is little affected by soil textures (Yang et al. 2007). Tensiometric measurement of SWP is also used as one of the criteria for scheduling irrigation (Kumar et al. 2016, 2017a, b; 2019). Advantages associated with scheduling irrigation based on tensiometric measurement of SWP was also reported in previous studies (Kumar et al., 2019). When irrigation scheduling was done on the basis of irrigation water/cumulative potential evaporation (IW/CPE) ratio of 1.2, it resulted in higher crop growth and yield (Maheswari et al. 2007).

4.3.1 Sensor based irrigation technologies

The newer dimension of precision irrigation in rice is the application of irrigation water through the use of sensor technologies based on site-specific needs. Various sensor technologies have been used to correctly identify the time of irrigation based on crop needs. For precision irrigation in rice, gypsum block sensors, time domain reflectometry (TDR), frequency domain reflectometry (FDR), neutron probe sensors, and so on were initially utilised. However, due to their increased cost and limited applicability, these sensors are not widely employed in rice fields (Maugan et al. 2015). A multi-sensor capacitance probe is used in rice fields to schedule irrigation by monitoring several factors such as ponded water level, soil moisture, temperature profile, and so on, but it is also expensive (Brinkhoff et al. 2018). The tensiometer, a relatively low-cost instrument, is a frequently used sensor for rice irrigation scheduling. It monitors soil moisture potential from 0 to -90 kPa (Whalley et al. 2013) and is useful in reducing irrigation water and labour expenditures (Kumar et al. 2017a, 2018).Granular matrix sensors are also gaining popularity for precision irrigation scheduling in rice due to their low cost, lack of maintenance, and ease of reading output manually or through automation utilising battery-powered metres or data loggers. In larger agricultural fields, there is fluctuation in soil texture and moisture that must be accounted for in order to apply irrigation water precisely. The use of RS and GIS aids in the assessment and forecasting of soil moisture, as well as mapping in surface and crop root zone depth, which is used to make decisions on the depth of water to be applied and irrigation scheduling. Rice irrigation management information system (RIMIS), a GIS-based water management interface, can increase irrigation efficiency in larger rice cultivated areas by accurately estimating the time and amount of irrigation water to be applied in the rice field (Amin et al. 2010). One of the new and rapid approaches is diffuse reflectance spectroscopy, which is used to measure a variety of soil qualities and crop parameters (Stenberg et al. 2010). This application can be used to monitor crop metrics using remote sensing platforms that provide continuous spatial coverage across huge areas (Leinonen and Jones 2004).

4.3.2 Precision land levelling and micro irrigation techniques

Laser levelled rice field requires less standing water (3-4 cm) than flooded rice (5-6cm) because of precise slope of 1-2% that allows uniform water distribution throughout the field. Laser levelled rice fields have been found to be beneficial in increasing output by 7-24%, saving irrigation water by 12-21%, and reducing irrigation time by 47-69 h/ha every season for rice. (Aryal et al. 2015).

Micro-irrigation, in which water is applied precisely on or below the soil surface at low pressure using small devices that spray, mist, sprinkle, or drip water, is becoming more efficient and cost-effective. Micro-irrigation systems provide extensive control over water applications.Drip and sprinkler irrigation are improved precision irrigation water application systems that improve water application efficiency, resulting in higher crop water use efficiency and rice production (Rajwade et al. 2014). These irrigation technologies have the advantage of conserving irrigation water along with increasing rice crop production. Centre-pivot irrigation, also known as central pivot irrigation, water-wheel and circle irrigation, is a method of precision water application in a spatially diverse field. This system, which is made up of pipe and sprinklers and is operated by an electric motor or hydraulic means, rotates around a pivot in the centre and irrigates the crops. This irrigation technology has been shown to save up to 67 percent of irrigation water in rice while boosting output by 1.8 to 2.25 times (Vories et al. 2013).

4.4 Precision weed management in rice

Weeds affect quality and quantity of agricultural produce. During the early stages of crop growth, weed competition with rice is greater (2-6 weeks after planting). Weed control during this time period is critical for maximising crop yield. Manual weeding is time-consuming and labour-intensive; thus, chemical weed control is gaining popularity in the country due to lower operational costs and time. However, herbicide waste as a result of blanket application causes pollution to the ecological environment of the farmland. All of these problems can be solved by employing precision agricultural principles in weed management. Precision weed management (PWM), can be simply stated as “the right amount of inputs on the right target [weeds] at the right time”. Synchronous application of herbicide not only reduces the non-target impact on the environment but also reduces the input cost without decreasing weed control efficacy. Precision agriculture has advanced rapidly in the last decade as a result of technological advances in sensors, computer hardware, nanotechnology, unmanned vehicle systems, and robots that may allow for specific identification of weeds in the field (Young et al. 2017). Distinguishing the weeds from crop has an important role in precision weed management. Use of computer vision technology in weed detection has considerably increased during recent times which helps in successful weeds detection to ensure that the herbicide spray is used only for weeds (Kamath et al. 2020). Mikail et al. (2021) created the Single Shot Multibox Detector (SSD) to classify and locate weeds in low-land rice precision farming, which is intended for post-emergence herbicide application for weed control in lowland rice fields.The precision weed management is based on (1) computerized decision support systems (DSS), (2) identification and mapping of weed and crop plants and (3) variable rate herbicide application and (4) site specific weed management. Quantitative understanding of weed population dynamics and crop-weed interactions is required for the development of improvements in all of these areas. Models can be used to integrate available quantitative knowledge to design preventive measures, develop long-term and short-term weed management strategies, aid in decision making to determine when, where, and how weeds should be controlled, and identify new weed control opportunities.

Crop-weed competition eco-physiological simulation models simulate the growth and production of species in mixtures. These models are based on plant eco-physiological processes and how they respond to their surroundings. These models helps in better understanding of the crop-weed system and can be used to build simple forecast yield-loss models, threshold levels, or the design of competitive crop plant types. Strategic weed management decisions for preventive measures and the identification of new weed control options require a quantitative understanding of the dynamics and spatial patterns of weed populations. The models are necessary due to the complexity of the process and the long-term nature of weed population dynamics. Because of the complexity of the process and the long-term nature of weed population dynamics, the models are essential. Many DSS models for managing weeds in cereals have been developed over the years, including CPOWeeds, DecidHerb, OptHerbClim, GestInf, MLHD, IPMIDSS, DoseKey, and WeedManager (Been et al. 2010). DSS models of this type can be developed and evaluated in rice.

The identification and mapping of various weeds is necessary for evaluating weed management strategies and their effectiveness in order to determine the chemical requirements for weed control. Maps are also used to investigate population dynamics and to discover the best models for predicting weed diversity. Weed maps can be used to navigate GPS-based sprayers. Differentiating weeds only on the basis of spectral reflectance is challenging due to the little variation in spectral reflectance among weeds. Zwiggelaar (1998) discovered that using spectral information alone is difficult to distinguish between crops and weeds, therefore spatial geometric effects from weeds and crops should be considered. Various parameters, such as disparities in weed and crop growth rates, time of emergence, vigour differences, and differential stages of inflorescence and senescence, impact whether weeds can or cannot be differentiated using remote sensing (Menges et al., 1985). Some proximal sensors, such as the WeedSeeker® system, which includes sensors ranging from simple colour detectors to complex machine vision systems, are used to discriminate and identify weed populations.

The spatial and spectral resolutions of satellite pictures are critical for weed classification. The IKONOS satellite has a spatial resolution of 1 m in panchromatic mode (450-900 nm) and 4 m in multi-spectral mode. Other satellites with varying spatial resolutions are available, including SPOT (20m), Landsat TM (30m), IRS-1B (36m), and AVHRR (1km). Multispectral airborne imaging systems with built-in image processing systems and high spatial and temporal resolution may aid in weed mapping.Herbicide is applied uniformly over the entire area in the conventional way; however, map-based weed control has the ability to reduce herbicide inputs in the field by avoiding the areas that are not afflicted with weeds. The rate of herbicide application in map-based weed management is adjusted based on a prescription map, utilising a GPS device to detect the field position, and the input concentration is modified as the applicator passes through the field. This is accomplished by using UAV imagery, machine learning, remote sensing, video cameras on tractors, or manual counts to map weeds in rice paddies at early stages of the growing cycle, and then spraying the field at a uniformly low rate with a higher dosage of herbicide in areas with weed patches to support variable rate technologies for site-specific weed management. A combination of high resolution red–green–blue (RGB) image and low resolution multispectral (MS) image taken from a fixed-wing unmanned aerial vehicle (UAV) at 60 and 70 m altitude is utilised to detect Gramineae weed in rice crop after 50 days of planting (Barrero and Perdomo, 2018).

Sensor-based approaches vary application rate based on pest stress or canopy characteristics identified by differences in pest colour, shape, size, texture, reflectivity, and temperatures sensed by different sensor types (colour cameras, photo-detectors, laser scanners, multispectral and hyperspectral cameras, thermal cameras, and ultrasonic sensors). The sensor input can also be used to direct and control the rate at which the chemical is applied.Color images were used to detect weeds and other pests. The weed density and weed coverage area in the field are computed using digital photos and a fuzzy algorithm to plan site-specific herbicide treatment. To create weed maps, use a microcontroller and GPS. These weed maps are required in order to apply the appropriate amount of herbicides where they are required. The development of precise and powerful sampling tools for automatic and continuous detection of variation in crop and weed populations is a significant step toward a feasible solution for site-specific weed management. Despite the higher costs of weed sensing and application technology, site-specific weed control produced higher economic returns than conventional uniform applications, even over long time periods. It is commonly acknowledged that site-specific weed management can lower weed control expenses. However, the offline mapping procedure is time-consuming, and widespread acceptance of site-specific weed management in practical agriculture will necessitate the development of an online system that combines weed species recognition and herbicide delivery in a single operation.

4.5 Pest and diseases management

Insect pests and diseases are typically dispersed unevenly across the cropped area. The current analytical methods have limits in formulating insect pest and disease control decisions that can be implemented uniformly in the field. Recently, spectroscopic approaches incorporating proximal and remote sensing technologies have been developed to map and analyse the geographical distribution of insects and diseases. Precision pest and disease management approaches are site-specific and are based on (1) pest and disease outbreak forecasting, (2) computerised decision support systems (DSS), (3) Crop pest and disease identification and mapping, and (4) variable rate pesticide application.Infestation by insect pests and diseases varies greatly depending on cropping season and region. Temperature is a significant weather component for insect pest growth, development, pest epidemics, the level of crop damage, and overall crop yield. Pesticides must be used on time to be successful in controlling insect pests and diseases.

Pest forecasting is classified into two types based on the forecasting period, i) short-term forecasting - predicting for one or two seasons ii) long-term forecasting based on the impact of weather parameters on the pest. So far, various modelling approaches for disease prediction in plant populations have been used, including Generalized Regression Neural Networks (GRNN) and multiple regression (REG), back-propagation neural network (BPNN), and support vector machine (SVM). The phenology of the herbivore and its host is taken into account by the majority of pest forecast models. In a temporal and spatial viewpoint, near real-time pest incidence data combined with remote sensing and GIS tools facilitate early warning of impending pest build-up.

Hyperspectral remote sensing is an effective technology for detecting crop stresses caused by insect pests and illnesses. The wavelength of electromagnetic radiation has an effect on how it interacts with plants. The reflectance of the same plant leaves might differ significantly depending on their state of health and/or vigour. In general, healthy and vigorously growing plant leaves will have i) low reflectance at visible wavelengths due to greater absorption by pigments (chlorophylls, anthocyanins, carotenoids), (ii) high reflectance in the near-infrared due to multiple scattering at the air-cell interfaces in the leaf's internal tissue, and (iii) poor reflectance in wide wavebands in the short-wave infrared due to absorption by water, proteins, and other carbon constituents.

Insect-affected crops have different tone variations in images than non-affected crops. Normal crops produce red, brilliant red, and dark red with a smooth texture, whereas pest-affected areas produce pink, yellow, and yellow pinkish-red with an uneven shape and rough texture. Different insect pests such as yellow stem borer (YSB) (*Scirpophagaincertulas*), brown planthopper (BPH) (*Nilaparvatalugens*), leaf folder (*Cnaphalocrocismedinalis*), and diseases such as a blast, bacterial blight, sheath blight, and false smut are the most notable risks in rice yield in tropical areas, particularly in Asia. Several researchers examined the impact of weather factors on the brown plant hopper (BPH) population and found that temperature, humidity, and rainfall were important ones. Based on the peaks of its light trap catches, a forewarning model for rice leaf folder was established, with maximum temperature, morning relative humidity, evening relative humidity, and SSH explaining 99 percent of the variability in leaf folder light trap peaks in Punjab. According to weather data, hotter and drier conditions in June and July of might have played a part in the leaf folder outbreak, in addition to other variables (Singh et al. 2015).

Many simulation models for the rice crop have been developed in order to study, predict, and manage diseases. Rice blast is the most devastating rice disease, causing massive losses each year. The most commonly utilised climatic variables are air temperature, relative humidity, and rainfall. The main pathogenisis parameters, such as leaf wetness, nitrogen fertilisation, and varietal resistance, were only partially incorporated in the development of these models. In Japan, Korea, and India, five forecasting systems are now functioning. Manibhushan Rao and Krishnan (1991) developed the EPIBLA (EPIdemiology of BLAst) model, which simulates leaf blast incidence by employing multiple regression equations depending on maximum temperature and maximum RH. In Japan, Yoshino and Tanaka (1979) created a model that estimated *Pyriculariaoryzae* infection periods by monitoring weather conditions every hour and producing hourly findings that indicated whether the conditions would result in successful infections. Kang et al. (2010) developed a forecasting model based on meteorological data that describes an online information system for plant diseases. EPIRICE, a generic model for plant diseases paired with GIS, was developed by Savary et al. (2012) in Korea.

Computer-based DSSs have the potential to be essential decision-making tools for farmers and their advisers (Ritchie, 1995). The Central Research Institution for Dryland Agriculture in India has developed a DSS for insect pests of rice and cotton-based cropping systems. The National Institute of Agricultural Extension Management (MANAGE) in India developed an expert system for identifying pests in rice crop and recommending preventive/curative measures. The rice crop doctor demonstrates the application of expert systems in agriculture in general, and specifically in rice production, through the development of a prototype that takes into account a few major pests and some deficiency problems that limit rice productivity. The system is designed with the technological possibility of automated crop spraying instructions to the computerised sprayer; completed spraying operations are saved in the DSS via an information flow.

5. Strategies for developing and promoting precision farming technologies in India

The use of PF technologies in farmers field in India is in nascent stage and still the sensors and drone based PF technologies are not matured. Hence the trained scientific manpower may be created in research institutes to develop and validate the PF technologies for the different regions and ecologies of rice. Land fragmentation, a lack of highly complex technological centres for precision agriculture, specialised software for precision agriculture, and farmers' poor financial status should all be considered in large-scale precision agriculture adoption strategies in India. For quick adoption, both public and business sector support is required. The problem of land fragmentation may be solved by virtual land consolidation with the ownership structure intact. To disseminate precision agricultural technologies, programmes may be initiated in which use of advanced sensors and technologies are promoted. The PF technologies for small farms for Indian farmers should be developed by the research institutes and agricultural universities. Agricultural Cutting-Edge Technology Parks might be developed in each section of the country to collect experience and develop techniques for accurately applying PF in a region-by-region structure. Training programmes may be organised to create manpower who can handle PF technologies and can implement in the farmers field. The progressive farmers from different regions may be identified and PF technologies may be promoted on their field on pilot scale for large scale dissemination. But the basic requirement for disseminating PF technologies is small and cheap sensor as well as the accurate PF technologies which have been validated in the field for input management.

6. Conclusion

Precision agriculture technology research and implementation on a broad scale remains a long-term possibility for the Indian agricultural sector. The vibrant IT sector and extensive Agri-IT research would pave the way for such smart farming concepts to revolutionise India's agri-industry. The establishment of specialised institutions and scientific databanks is a well-known requirement for precision farming. Increased use of precision farming technologies in India can help to reduce production costs, increase productivity, and improve natural resource utilisation. Rapid socioeconomic developments such as economic growth, urbanisation, and energy consumption are opening up new potential for precision farming in India.

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Chapter 17

Insect Pest Dynamics in Rice-Based Production Systems Under Changing Climate

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Abstract

Climate change has substantial impact on insect species diversity and their distribution and poses a great threat to human food security by reducing agricultural production and productivity globally. The rise in earth's temperature, elevated carbon dioxide and change in the frequency of rainfall patterns and distribution of precipitation pattern are three major components of global climate change that has been affected insect pest dynamics in several ways. Rice is the foremost essential cereal crop and half of the worlds' population depends on it as a staple food. But its production remained on the lower side due to biotic stresses. Changes in climate affect the insect pests of rice in terms of expansion in geographical range, increased or decreased number of generations, growth and reproduction ability, fecundity, interspecific and tritrophic interaction, increased frequency of vector-borne diseases, and reduced effectiveness of biocontrol agents. Several adaptive management practices including modified integrated pest management tactics, monitoring of insect population and use of web-based modelling tools may be implemented to deal with the changing status of pest population owing to climate change.

Keywords: Carbon dioxide, Insect dynamics, increased temperature, Rice pest, Yield loss

1. Introduction

Profound shift in the dietary patterns, increasing population and growing wealth has substantially increased the global demand for food. In order to cater the worldwide food demand, the production has to be increased to 40% by 2030 and 70% by 2050 (FAO, 2009). Rice being an important staple food in India, accounts for nearly a quarter of the gross cultivated area and contributes for 42% of total food grain production which is 45% of overall cereal production. Though rice cultivation in India extends to an area of 41.85 m ha with a production of 102 m tones (Pathak, 2020), its productivity remains low due to many abiotic and biotic constraints (Jena et al. 2018). Climate change has worsened the existing risks to biodiversity, which affects both the human health and livelihood. The production and productivity of rice have been affected and consequently threatened food security. The world temperature is projected to have climbed by 0.74°C between 1906 and 2005 as a result of rising greenhouse gas emissions, and the carbon dioxide concentrations are anticipated to escalate on 445-640 ppm by 2050. According to reports, crop production losses due to pests have increased internationally as a result of rising temperatures. Crop output losses due to pest infestation are anticipated to reach 46, 19, and 31 percent in wheat, rice, and maize, respectively, with a 2°C increase in average global surface temperature (Deutsch et al. 2018).

Besides global temperature, elevated atmospheric CO_2 levels alter the photosynthetic carbon assimilation patterns thereby causing a direct impact on the plant development. Increase in growth and yield in rice under elevated CO_2 conditions was previously reported, however temperature rise cause an adverse effect on C_3 plants. But the interaction between atmospheric temperature and CO_2 concentration actually influences the plant growth and yield. In the climate change scenario, temperature directly affects insects, while CO_2 affects them through host plants (Netherer and Schopf, 2010). It is previously reported that insects are capable to evolve by increasing its generation with every 2°C rise in temperature by an increase of one-to-five life cycles per season (Yamamura and Kiritani, 1998).

Atmospheric CO_2 levels have an impact on plant quality as well as herbivore performance (Awmack et al. 2004). When plants are cultivated in elevated CO_2 environment, the C: N ratio of the plant canopy normally rises (Pandi et al. 2018). As a result, leaf consumption and sap sucking by insect pests has been increased to compensate for lower nitrogen in plant foliage (Pandi et al. 2018). Furthermore, natural enemies of pests, which play a key role in biological pest control, are vulnerable to climate change and its fitness affected by herbivore quality and size changes due to CO_2 and temperature effects on plants (Thomson et al. 2010; Pandi et al. 2017). Herbivore sensitivity to natural enemies might be reduced by thick plant foliage. Changes in herbivore quality may directly affect the number and activity of natural enemies as a result of changing climate (Klaiber et al. 2013). These tactics may cause a spatial and temporal mismatch between plats pests and natural enemies, thereby reducing efficiency of biocontrol management. Making projections will be difficult until a thorough understanding of climate change and its impact on tritrophic interactions is attained (Boullis et al. 2015).

2. Status of insect pest in rice cultivation

Insect pests attack practically every component of the rice plant at some point throughout its life cycle. Around 800 bug species have the potential to harm rice in the field or during storage, but only a dozen or so are regarded serious menaces. Based on the feeding habit, rice insect pests are categorised into numerous groups based on their feeding habit as grain insects like stink bugs extracting milk from maturing grains, defoliators like cutworms, and stem borer that feed on leaves and bore into stems, respectively (Jena et al. 2018). Sap sucking insects, on the other hand, are common in rice fields because they feed on phloem sap as their main food.

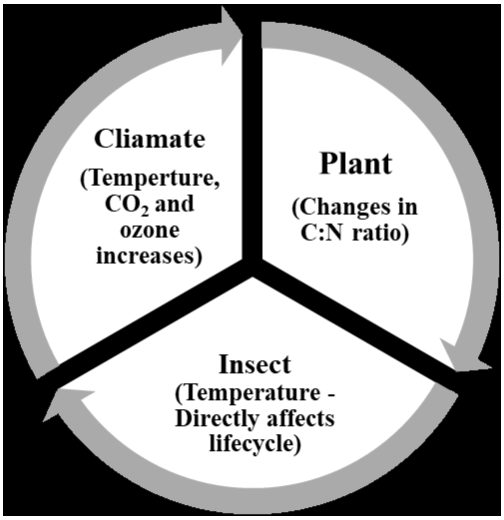

Figure 1. Interaction between weather, plant and insect pests

2.1. Climate change impact on insect and natural enemies

Insects have cold blood and their bodies are about the same temperature as their surroundings. As a result, temperature is most likely the most critical environmental element regulating the insect growth, development, reproduction, dispersion, and survival (Das et al. 2011). Accumulated degree-days (DD) and biofix point are the most frequent approach for predicting insect life stages (Charles et al. 2006). Generally, climate change impact on tritrophic interactions assessed through two approaches. One strategy is to use mathematical models (Stireman et al. 2005), while the other is to use experiments to demonstrate the responses of all three trophic levels like the host- pest-biocontrol agent (Fig. 1).

Climate change may have an impact on insect growth and host suitability parameters like synchrony between crop and pest, geographical distribution, interspecific interactions, population out-breaks, number of generations, period of activity, diapause success, host plant resistance, and migrant pest invasion. According to research, climate change has a negative impact on rice insect pests by increasing their developmental period, decreasing egg hatching percentages, survival, and female longevity (Table 1). The Climate change's ultimate impact on crop development and yield would be determined by its interactive effect on tritrophic interactions. Climate change can affect the effectiveness of agro-chemicals through rise in temperature and precipitation patterns (Coakley et al. 1999). When it comes to pest management research and development, global warming should be taken into account, as adaptation to climate change may necessitate modifications in package of practices for rice cultivation, like sowing time and frequency of pesticide applications. Climate change must be carefully considered in order to ensure future food security.

2.2. Climate change effect on invasive rice pest

Many studies suggest that climate change may contribute to the global invasion of many invasive species in the future. The apple snail, *Pomacea canaliculata* (Lamarck) (Gastropoda: Ampullariidae) has been one of the most notorious irrigated rice invaders in Southeast Asia for over 30 years (Schneikeret al. 2016; Lei et al. 2017). Initially, they were introduced from South America to South Asia as a potential proteinaceous food source, but now this pest has been invaded many rice growing parts of the world. It is predicted that, suitable habitat for golden apple snail will increase up to 8% by 2050 and up to 10% by the year 2080 due to temperature variation (Lei et al. 2017). Similarly, the small brown planthopper, *Tagosodes orizicolus* (Muir) (Homoptera: Delphacidae) is a severe pest of rice in Central America was first reported in North America during 1957-1959 in small pockets and cold winters prevented permanent establishment of this pest in these region; but after 2015, this pest started appearing at regular interval in USA and could establish over-wintering site at Texas (Lsuagcenter 2022). Likewise, north America bound rice water weevil, *Lissorhoptrus oryzophilus* Kuschel (Coleoptera: Curculionidae) was recently introduced to east Asia and studies suggest that climate change favouring their reproductive plasticity thereby increasing their geographic spread and population development (Huang et al. 2017).

3. Climate change impact on insect distribution

In general, insect pests are more sensitive to climate change than plants, and insects' distribution is impacted by host plant distribution. Change in temperature affect the onset of flight as well as dispersal mechanism in insect pest population and it vary both among and within species. Climate change largely intervenes plant populations by affecting their phenology and fitness components, consequences of which lead to changes in pest population dynamics (Hornemann et al. 2012). Global warming has direct impact on the spatial and temporal distribution of insect, their herbivores and will have further influence in future (Hillstrom and Lindroth, 2008). It has been observed that, number of insect species per unit area decrease with increasing latitude. Several types of research conducted on increasing altitude and latitude and its impact on pest dynamics showed that areas with warmer temperatures tend to have more species diversity and higher numbers of pest population as compared to areas with cooler temperatures (Petzoldt and Seamann, 2012). The geographic range of some insect species is limited by low temperatures, and rising temperatures may increase the ability to undergo diapause at high latitudes and increase the likelihood of expansion (Singer and McBride, 2012). Changes in climatic conditions lead to changes in the spatial distribution of pest species.

Climate change (both increased temperature and rainfall) may not result in an increase in the frequency of *Scirpophaga incertulas* Walker (Lepidoptera: Crambidae) outbreaks in rice fields; rather, outbreak frequency may get reduced (Ali et al. 2020). Likewise, elevated temperature has also affected the brown planthopper, *Nilaparvata lugens* (Stål) (Hemiptera: Delphacidae) and rice leaffolder, *Cnaphalocrocis medinalis* (Guen) (Lepidoptera: Crambidae) survival (Table 1). Climate change, on the other hand, has both good and negative effects on rice predators. Climate change had no effect on the feeding rate of the wolf spider, *Pardosa pseudoannulata* (Bösenberg & Strand) (Araneae: Lycosidae) but it did influence the foraging capacity of its mirid predators *Cyrtorhinus lividipennis* Fieber (Hemiptera: Miridae) and *Tytthus chinensis* (Stål) (Hemiptera: Miridae) (Table 1).

Table 1. Climate change effect on population dynamics of rice insect pests and natural enemies

Climate variable	Insect pest	Effect	Reference
Elevated Temperature	Brown planthopper, *Nilaparvata lugens*	Increase ovipositional rate and survival on resistant variety	Horgan et al. 2021
	Leaf folder, *Cnaphalocrocis medinalis*	Declined survival rate	Karuppaiah and Sujayanad, 2012
	Yellow stem borer, *Scirpophaga incertulas*	Decrease the developmental time and egg hatching percentage Increase the number of generations, fecundity and abundance	Manikandan et al. 2016 Ali et al. 2020
	Rice ear head bug, *Leptocoris acuta*	Increases in generation time	Karuppaiah and Sujayanad, 2012
	Mirid Bug, *Cyrtorhinus lividipennis* & *Tytthus chinensis*	Increases in attack rate Decreases predator searching capacity Temporal asynchrony between host and predator	Bai et al. 2015

Elevated CO_2	Brown planthopper, *N. lugens*	Population increased enhanced female longevity, fecundity and nymphal feeding rate Higher fecundity	Pandi et al. 2018
	Leaf folder, *C. medinalis*	Increase the consumption rate Reduced egg hatching percentage and larvae to adult emergence	Sharma et al. 2010
Elevated Temperature×CO_2	Brown planthopper, *N. lugens*	Population increased Prolonged nymphal duration Lowered female longevity, fecundity and nymphal feeding rate	Shi et al. 2014 Pandi et al. 2018;
Elevated Temperature× elevated rainfall	Leaf folder, *C. medinalis*	More leaffolder populations	Ali et al. 2019
	Yellow stem borer, *S. incertulas*	Negative growth rate and population survival	Ali et al. 2020

3. Climate change effect on insect pest populations

3.1. Effect of elevated temperature on insect ecology

There is a great influence of global warming on abundance, herbivore growth, and availability of prey and hosts in tropical climatic region (Boullis et al.2015). Higher precipitation and temperature in tropics strongly affect the insect growth, development, survival and reproduction (Sharma et al. 2010). For instance, the abundance of green leafhopper, *Nephotettix virescens* (Distant) (Hemiptera: Cicadellidae) and stripped stem borer, *Chilo suppressalis* (Walker) (Lepidoptera: Crambidae) in rice crop, increases with higher winter temperature, while rice bug, *Leptocorisa oratorius* (Fabricius) (Hemiptera: Alydidae) population increases with high summer temperatures (Yamamura et al. 2006). The extinction rate of species is 100 to 1,000 times higher as compared to what has happened earlier, and about 45 to 275 species are being extinct everyday due to climate change (Sharma et al. 2010). It has been shown to expand their geographic range from tropical and subtropical to temperate regions as cultivation of their host crops are shifted in these area (Sharma et al. 2010). This leads to an increased abundance increases the number of tropical insect species (Diffenbaugh et al. 2008) and causes the sudden outbreak of certain pest species (Kannan and James, 2009). It has been reported that, rising temperatures accelerate the growth, reproduction, and survival of pests in tropical and subtropical regions, allowing them to complete more than one generation a year and ultimately more crop damage (Pandi et al.2017). Several studied on lepidopteran pest of rice have shown that, increase in winter temperature is a crucial factor for the survival and colonization of new areas.

3.2 Effect of precipitation pattern on insect pests

Changes in rainfall patterns have a substantial impact on pest diversity and abundance. Analysis of precipitation pattern data over the last 100 years has shown that the frequency of heavy rainfall increases the number of pests compared to light rainfall (Das et al. 2011). However, species such as rice thrips are very sensitive to rainfall and get killed or removed from the crop due to heavy rainfall. At the same time, dry spell during summer rapidly increased the wireworm, *Agriotes lineatus* (Linnaeus) (Coleoptera: Elateridae) populations in the upper soil layers.

4. Physiological changes in insects due to climate change

4.1 Adaptive response to photoperiods and diapause behaviour

As insects are poikilotherms, they developed several physiological and behavioural mechanisms such as diapause and migration, respectively to adapt the thermal stress. Diapause s a period of interrupted developmental activity regulated by various environmental factors such as humidity, temperature, and day length. Hence, the insects, which undergo a winter diapause experience outstanding changes in their thermal environment. Insect experienced two type of diapause such as hibernation and aestivation under extremely low and high temperature, respectively. The egg viability of blackfin waryfish, *Scopelosaurus Lepidus* (Krefft and Maul) (Aulopiformes: Notosudidae) was extremely affected by drought conditions and do not undergo hatching under dry spell (Karuppaiah and Sujayanand, 2012). A period of dormancy is crucial for many temperate insect species to survive and complete their life cycles and to go through the extreme low temperatures condition of the winter season. The aestivation mechanism allows insects to survive in an environment with higher temperature environments, and hibernation allows them to survive in lower temperatures. There was no report of these phenomenon on rice insect pests; hence here we have discussed the same with other insect species. Battisti (2004) reported that, the spruce webspinning sawfly, *Cephalcia arvensis* Panzer (Hymenoptera: Pamphiliidae) enters pupal diapauses when the soil threshold temperature reached below 10°C. European butterfly, *Aricia agestis* (Denis and Schiffermüller) (Lepidoptera: Lycaenidae) shift its diapause inducing temperature threshold to adopt a new thermal environment (Regniere, 2009). It has been found that, many insect species required higher temperatures at some stage in the photoperiodic induction of diapause (commonly in autumn) to lessen the period and frequency of diapause. For instance, European bluebottle fly produce smaller number of diapausing offspring when reared at 20 °C (Bale et al. 2010).

4.2. Climate change impact on expansion range of insects

Increase in temperature resulted in to range expansion of several species. A good example of shift in range boundary is appeared in the dispersal of green stink bug, *Nezara viridula* (Linnaeus) (Hemiptera: Pentatomidae) in response to increasing temperature in Japan. Similarly, golden apple snail, *P. canaliculata* will increase up to 8% by 2050 and up to 10% by the year 2080 in rice field of South Asia due to temperature variation (Lei et al. 2017). Likewise, climate change related pest range expansion also reported in other rice pest like brown planthopper, *N. lugens* (Pandi et al. 2021); small brown planthopper, *T. orizicolus* (Lsuagcenter, 2022) and rice water weevil, *Lissorhoptrus oryzophilus* Kuschel (Coleoptera: Curculionidae) (Huang et al. 2017). Similar reports also observed in other pests like corn earworm, *Helicoverpa zea* (Boddie) (Lepidoptera: Noctuidae) and american bollworm, *H. armigera* Hubner (Lepidoptera: Noctuidae) that also undergo range expansion with increase in temperature (Parmesan and Yohe, 2003). A similar case also observed in gypsy moth, *Lymantria dispar* L. (Lepidoptera: Erebidae), and nun moth, *L. monacha* L. (Lepidoptera: Erebidae) where increase in average temperature by 1.4, 3.6 and 5.8°C started the shifting of range towards north pole by 500–700 and 100–900 km, respectively, in Finland (Vanhanen et al. 2007). A study on 35 species of European butterflies (non-migratory) and the result showed that 63% of species have shifted their geographical range towards the north by 35 to 240 km and only 3% towards the south. (Parmesan et al. 1999). Shifting of range have been observed in forest geometrid moths such as *Operophtera brumata* (L.) (Lepidoptera: Geometridae), and *Epirrita autumnata* (Borkh.) (Lepidoptera: Geometridae) in Europe (Jepsen et al. 2008).

4.3. Effect of climate change on voltinism in insects

Increasing temperature result in to faster development and additional number of generation in rice leaf folder, *C. medinalis*; brown planthopper, *N. lugens*; yellow stem borer, *S. incertulas* (Table 1). Under Elevated CO2 condition brown planthopper shows higher rate of multiplication and additional number of generation in contrast to ambient CO_2 (Pandi et al. 2016; Pandi et al. 2018). In response to global warming, several insect species increase their annual multiplication rate by increase their ability to survive in winter, as a result of which, its population dynamics increases. Similar cases of elevated temperature induced reduction of multiplication time and more generation per year also reported in some multivoltine aphid and cabbage butterfly, *Pieris brassicae* (Linnaeus) (Pieridae: Lepidoptera) and polyvoltine species such as spruce bark beetle, *Ips typographus* (Linnaeus) (Curculionidae: Coleoptera) (Lange et al. 2006); spruce beetle, *Dentroctonus rufipennis* (Kirby) (Curculionidae: Coleoptera) (Berg et al. 2006).

5. Adaptation and mitigation strategies

Global climatic conditions changed several times with the history of earth, and along with it the diversity of insects. Influence of climate change on agricultural insect pests is so unpredictable and underestimated in relation to population dynamics, insect-plant interaction and their distribution (Skendzic et al. 2021). In last decades, upsurge of minor pests and new virulent has been experienced in rice ecosystem and the number of insect pest has been increased considerably over the period of time (Jena et al. 2018). Rice ecosystem is always dominated with higher population density of major insect pests with overlapping generations. Therefore, continuous monitoring of pest species and population variability in paddy fields is a priority. For adopting an effective pest management strategy, the present pest situation is need to be analysed with reference to its past history, its host range and area of distribution.

5.1. Pest surveillance and model development

The resultant population dynamics of insect pest relies on two components; (I) exogenous factor driven by climate change and, (II) endogenous factor that are driven by intrinsic mechanisms (Yamamura, 2006). Predicting the spread and progression of pests and diseases based on meteorological data is very important when planning and implementing control measures. Monitoring the onset of pest incidence and its intensity is very crucial for effective pest management. Pest surveillance is an important component for timely execution of integrated pest management strategy. It involves long term monitoring of pest population dynamics and their response to climate change (Heeb et al. 2019). A robust pest surveillance in rice field in Japan was conducted, in which a 50 years of light trap data of major insect pests was analysed for pest dynamics study, showed an increase in winter temperature enhanced the abundance of *C. suppressalis* and *Nephotettix cincticeps* Uhler (Hemiptera: Cicadellidae) (Yamamura et al. 2006). A paradigm shift has been observed in rice ecosystem, in which the number of insect pest has been increased upto 21 from 1965 to 2017 (Jena et al. 2018). Similarly, the brown planthopper has gained the major pest status after 1970 and continuously developing resistance to well-known resistant cultivars (Anant et al. 2021a).

Different climate based models have been used to predict the possible effect of changing environment on insect pests. The correlative species distribution modelling is widely used to predict the impact of climate change on species biodiversity (Gillson et al. 2013). Similarly, CLIMEX, a modelling software tool that use the behavioural and physiological parameters and climate variables to predict future species distribution pattern (Desprez et al. 2007; Kriticos et al. 2015). NCSU-APHIS Plant Pest Forecast (NAPPFAST) is a web based modelling system, is used by North Carolina State University was used for pest risk assessment by linking everyday climate and past weather data with biological models (Borchert and Magarey, 2005). RICEPEST, a pest simulation model has been developed by IRRI that gives promising result on rice yield losses due to pest attack under a specific production system (Willocquet et al. 2004). But most of the climate based models are sophisticated and mostly relay on single weather turbulence. So the knowledge on climate change impact on insect pest in a long run has been insufficient yet. However, analysing pest and crop component at the same time in a given location to improve decision making is more practical. Now-a-days many developed countries have been adopted some dynamic websites on internet that include real time weather information and GIS-based decision system to get real time advantages regarding crop management. To achieve higher accuracy, the available simulation models need to be validated with site- and species-specific inputs. In addition, strong agricultural meteorological networks for specific plant ecosystems need to be established in developing countries for real-time pest prediction and decision-making systems.

5.2. Host plant resistance

Host plant resistance could be a suitable approach in combating present pest situation as because developing a resistance variety is more economical and environmentally safe option in a sustainable crop production system. Earth atmospheric temperature is increasing day by day in addition to increase in global carbon dioxide (CO_2) level, which directly or indirectly affecting insect population and its reproductive rate (Allen et al. 2009; Deutsch et al. 2018). Moreover, by the year 2020, the global pesticide usage has been increased up to 3.5 million tonnes (Sharma et al. 2019). Thus developing insect resistant varieties instead of using hazardous chemical pesticides is a better approach (Anant et al., 2021; Babu et al., 2022).

In rice ecosystem, BPH is one of the belligerent pest and is continuously evolving with its host plant. Although more than 40 resistant genes are identified for BPH, this pest is continuously evolving in a variable manner due to dramatic climate change and unpredictable weather condition (Wang et al. 2010). Furthermore, elevated temperature is also reducing the resistance response in BPH-resistant cultivars (Kuang et al. 2021; Horgan et al., 2021). BPH resistance genes in IR26 and IR36 were reported to lose their resistance at higher temperature (Wang et al. 2010). In order to develop a sustainable resistance variety, the impact of climate change on theses resistance genotypes is need to be considered. Kuang *et al.* (2021) examined nine near isogenic lines (NILs) having single BPH-resistance genes under some environmental settings based on climate change prediction for year 2050 and 2100 and reported only two of nine NILs (NIL-*BPH20* and NIL-*BPH17*) maintained their resistance status despite the climate change effect (Kuang et al.2021).

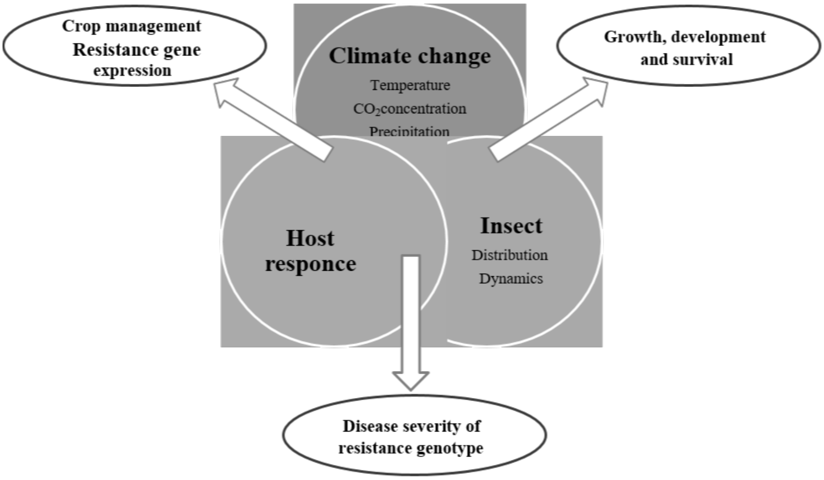

Figure 2. Climate change effect on insect pest *vs* host plant resistance

5.3. Changes in the cultivation practices

The increased temperature and change in precipitation conditions leads to change in insect pest population dynamics. The efficacy of existing control measures including cultural practices, host plant resistance, use of biocontrol agents, conventional insecticides and biopesticides has been reduced as a result of climate change (Barzman et al. 2015). Thus, need arises to develop an appropriate pest management strategy to mitigate the problems under the situation of climate shift in future. It is crucial to set up a future line of research in developing climate resilient varieties through plant breeding programme that could resist the abiotic and biotic stresses. Shift in rainfall pattern resulted the problem of early insect infestation in many crops (Pareek et al. 2017). Hence it is advisable to reschedule the crop calendar according to the crop environment.

More the biodiversity more is the stability of an ecosystem. Biodiversity of an agricultural ecosystem can be increased by adopting intercropping, mixed cropping and crop rotation to conserve and enhance the natural enemy population. Some biopesticides and entomopathogenic agents are less effective under high temperature conditions and they require synergist and other adjuvants to increase their efficacy (Skendzic et al. 2021).

5.4. Changes in the pesticides application practices

Higher concentration of CO_2 condition resulted in more biomass production in terms of increased root and shoot length, increased tillering compare to ambient CO_2 in many crops including rice (Pandi et al., 2019). Similarly, increase in temperature also cause increased tillering during vegetative stage (Pal et al., 2003). The enhanced plant density creates more congenial microhabitat for leaf feeding as well as sucking insects. Therefore, to control increased pest attack, we need to revise the insecticide application rate in accordance with the insect population in the field.

6. Conclusion

Climate change is the most dynamic and worldwide environmental challenge. It has a considerable impact on the occurrence, distribution, development, reproduction, voltinism, and phenology of insect pests. Insect pest management tactics on the one hand, are impacted by changes in host plant defence mechanisms and other hand by invasive insect species, natural enemies-pest asynchrony, reduction in predator-parasitoid efficiency. Furthermore, as climate change affects insect populations, crop losses are anticipated to worsen, jeopardising the food security of countries that rely largely on agriculture. A practical and scientific plan will be necessary to handle this problem. As a result, it is critical to plan and create long-term mitigation strategies, such as enhanced IPM systems, monitoring and modelling tools for surveillance and prediction.

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Chapter 18

Dynamics of Emerging and Remerging Rice Diseases Under Changing Climate Scenario

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Abstract

Global food security in terms of balance between growing food demand and agricultural output, combined with discrepancies between supply and demand at regional and national levels, is alarming. For many reasons, pathogenic infections to the crops are significant. Pathogenic infections produced plant diseases that resulted in crop losses directly or indirectly. Plant disease is the output of three-way interaction of host, pathogen and environment. Thus, changes in environmental conditions directly influence the disease equilibrium. Rice is not an exception and is attacked by several pathogens from its pre-seedling to maturity stages which extend up to storage. All stages of life cycle of host and pathogen are influenced by weather. Thus, changing environment has a definitive role in changing disease scenario. Climate change influenced many diseases of rice and their status also changed from minor to major emerging diseases. During pre-green revolution era brown spot was major disease of rice in India because of cultivation of fertilizer non-responsive indigenous varieties. However, with the use of fertilizer responsive high yielding varieties, the disease incidence was decreased. But the disease is re-emerging because the brown spot pathogen exposed to highly favourable temperature which is nothing but a result of changing climate condition and needs more research and proper care for its management. Likewise, false smut, bakanae and sheath rot diseases are not so important to rice in the preceding era but recently receiving emerging status. Now-a-days intensive researches are going on for finding out their infection process, life cycle and epidemiology for proper management strategies.

Keywords: Bakanae, brown spot, climate change, disease dynamics, false smut, rice diseases, sheath rot

1. Introduction

The Chinese saying "food is the first necessity of humans, and rice is always people's first choice" is very pertinent because rice is the staple food for around 4 billion populations throughout the world. Obviously, a major share of the economy is rice driven in many south-east Asian countries. It is known that plant disease is the output of interaction among the host plant, pathogen and environment; referred as the disease triangle. But, havoc changes in environmental conditions worsen plant disease symptoms (Boyer, 1995; McElrone et al., 2001) and generated 44% new disease (Anderson et al., 2004). Besides the widespread impact on human life, climatic change can enormously increase the plant disease incidence and severity and disease pressures, as also has influence on co-evolutionary relationships between plants and pathogens (Eastburn et al., 2011). A very specific example of the predictive result of global warming is of a geographical shift in the occurrence of brown planthopper transmitted rice stripe virus disease in Japan (Yamamura and Yokozawa, 2002) and as well many pathogens are directly influenced. Some of the pathogens that cause rice diseases like *Rhizoctonia solani* (sheath blight), *Bipolaris oryzae* (brown spot), *Burkholderia glumae* (bacterial seedling rot and grain rot) are now major and emerging diseases because the favourable temperature for growth of these pathogens is relatively high (around 30^0C) are usually prevailed during rice growing season. In general, most of the rice bacterial blight resistance genes losses their virulence with increasing temperature but Xa7 is more active at higher temperature (35:31 ^{0}C; day: night) than at lower temperature (29:21 ^{0}C; day: night). Kobayashi et al. (2006) reported that elevated CO_2 induced leaf blast and sheath blight severity and analysed that elevated CO_2 may be the possible reason of low deposition of Si in rice plant and it helps in increasing susceptibility to blast and alteration of rice canopy structure may quicken the spread of sheath blight in fields. Apparent changes in climatic conditions and changed cultivation practices have altered the intensity and distribution of various rice diseases as well as increased the occurrence of diseases like false smut, stem rot and bakanae. These climate change induced growth pattern of pathogens, their morphology and epidemiological factors attribute changes in severity and intensity of diseases in the long run. Rice diseases scenario has changed several times in India also. During pre-HYV era (up to 1965) brown spot (BS), blast, stem rot and foot rot was noted as major rice diseases particularly in eastern region of India where rice is the major crop for livelihood. During the period of 1965-1990, blast, tungro, bacterial blight (BB) appeared in severe while brown spot, stem rot and foot rot are found in lower scale except few endemic areas. After 1990, sheath blight (ShB) appeared as major in eastern and few north-eastern states of India. In present decade, bakanae and many post-flowering diseases like, rice false smut (RFS), sheath rot (ShR), panicle blight, kernel smut and grain discoloration are observed in all rice growing region of India (Bag et.al., 2017). Presently rice false smut is the problem for rice production throughout the world because most of the commercial rice varieties are found as susceptible. In India, rice false smut, bakanae and sheath rot are appearing in severe form in many rice growing states while brown spot is re-emerging as new threat particularly in upland and direct sown rice growing areas. The present chapter will discuss the dynamics of rice false smut, sheath rot diseases, bakanae, and brown spot diseases of rice.

2. False smut disease of rice

During 1960-70, rice false smut (RFS) was not considered as problem rather presence of these balls was indicated as as sign of good harvest. But, the severe outbreak of RFS during nineties in Japan and USA attracted many plant pathologists to initiate research on it. Recently, RFS has turned as "bumper disease" to the rice farmers in China (Bag et. al., 2021). The RFS, caused by *Ustilaginoidea virens*, had comparatively low effect on rice production prior to 1950 (Tanaka et al., 2008). An outbreak was reported from China during 2004, with 41.6% disease incidence and estimated loss was 1.37 billion kg of rice (Zhang et al., 2006). In Indian varieties Moti and Gayatri, 5.1% and 4.6% yield loss occurred respectively (Baite et al., 2020) while 0.5% to 75.0% losses (Baite et al., 2021) and 0.7%–8.6% yield losses were calculated in many Indian varieties (Bag, et al., 2021). The vast rice-growing areas of India are heavily affected by RFS during the last three decades, and it is in increasing trends (Bag et al., 2017; Laha et al., 2016). Variable disease incidences are reported like, 10%–20% and 5%–85% in Punjab and Tamil Nadu, respectively (Ladhalakshmi et al., 2012) and 5%–80% from Uttar Pradesh (Singh et al., 2014). 44% yield loss of rice was reported from Punjab (Pannu et al., 2011). Economic loss happens not only for reduction in yield, but also for negative effect on qualitative parameters. Black chlamydospores and sclerotia of false smut adhere to healthy seeds and these might be the cause of significant reduction in germination per cent (3.4–9.5) and seedling vigour index (6.8%–38.5%) (Bag et al., 2016). Significant changes ($p < 0.05$) in various cooking qualities of rice were also observed. Nutritional qualities like amylose and total phenol increased significantly ($p < 0.01$) whereas antioxidant activities decreased significantly ($p < 0.01$) in 'diseased' grains compared to its 'healthy' grain (Bag et. al., 2021a). *U. virens* secrets many toxins of which ustilotoxins is predominant (>100 mg/kg false smut balls), and mycotoxins are cytotoxic, inhibits both animal and plant cell division (Koiso et al., 1994).

2.1 Changes in false smut disease scenario in India

Cooke (1978) first reported false smut disease of rice from Tirunelveli, Tamil Nadu. This disease has attracted many researchers during the last two decades with its outbreak across the globe including Asia, America and Europe. Number of epidemics had increased in different parts of Asia, America, and Europe (Brooks et al., 2009). In India, the intensity and spread of this disease has dramatically increased during the last two decades. The disease was endemic in a few places and more or less sporadic with few cases of severe intensity but no major outbreaks in Bihar, Punjab and Uttar Pradesh during 1981-1990. But the scenario changes a lot during 1991-2000, the disease increased significantly in many states like Andhra Pradesh, Assam, Bihar, Haryana, Himachal Pradesh, Punjab, Uttar Pradesh and West Bengal. But in last two decades (2001-2014), the intensity and geographical spread of the disease increased dramatically in many rice growing areas and it was evidenced by large number of high intensities of occurrences. The disease has also significantly increased in high intensity in states like Bihar, Gujarat, Himachal Pradesh, Jammu & Kashmir, Kerala, Odisha and West Bengal whereas was widely present in low to moderate intensities in places of Andhra Pradesh, Telangana, Chhattisgarh, Karnataka, Punjab and Uttarakhand. The disease was remarkably high on hybrids compared to inbred varieties. (Laha et al., 2016).

2.2 Symptom

False smut disease is noticed by yellow, orange-yellow to yellowish-green or greenish-black and finally black false smut balls in the paddy field. Pathogen of false smut disease infects rice flowers and colonizes inside the flowers with mycelia, and finally transformed into false smut balls which is covered by powdery chlamydospores, thus the symptoms visible during flowering to maturity stage of crop (Sun et al., 2020). Initially false smut ball is a white fungal mass inside the spikelet at the early head stage; later the infected spikelet converted into yellow and finally greenish black to black false smut balls (Bag et al., 2021).

2.3 Taxonomy, etiology and disease cycle of the causal organism

RFS is caused by fungus and its anamorph is *Ustilaginoidea virens* whereas teleomorph is *Villosiclava virens*. Cooke (1878) first named *Ustilago virens*, whereas Patouillard (1887) independently named it *Tilletia oryzae*. Brefeld (1895) proved *Tilletia oryzae* is under fungi imperfecti (deuteromycetes), and not to basidiomycete family Ustilaginales. Brefeld (1895) proposed a new anamorphic genus *Ustilaginoidea*. Later Takahashi (1896) pointed out that *Ustilaginoidea oryzae* was identical with *Ustilago virens*, and thus combined the scientific name as *Ustilaginoidea virens*. Sakurai (1934) first found the asci in sclerotia of RFS fungi. He suggested rice false smut fungus was similar to Claviceps Tul. (Clavicipitaceae), but did not propose a scientific name for the teleomorph. Nomenclature of Claviceps was compared, and found it is not appropriate to any existing clavicipitaceous genera. Tanaka et al. (2008) proposed and amended the teleomorph by a new genus *Villosiclava*, a new combination *V. virens* (Tanaka et al., 2008).

Chlamydospores, a thick doubled walled asexual spore is produced directly from a vegetative hyphal cell and these are round to elliptical, warty 3 - 5µm sized over wintering stages of chlamydospores developed laterally on minute sterigmata of radial hyphae of the spore balls. These are ornamented with ~0.2–0.5µm spines that are irregularly curved or pointed at the apex. In culture chlamydospores usually germinate by germtubes and form ovoid and very minute bearing conidiophores.

Low temperature induces sclerotium formation and overwinter with 2-5 months dormancy. In presence of favourable weather condition sclerotia germinates and form yellow-coloured mycelial clusters round sclerotium margin and then developed yellow fruiting bodies which generate the stromata consisting perithecia. Perithecia contents so many asci and each one bear eight ascospores. Single sclerotium can produce millions of ascospores that can remains in paddy fields throughout the rice growing stage, thus have enough chance to infect rice flowers during the booting stage. Therefore, ascospores might be the primary source of inoculum in the disease cycle (Yong et al., 2018). Ascospores and chlamydospores produce conidia that serve as secondary source of infection.

2.4 Epidemiology

Degree of appearance of false smut balls are highly influenced by environment and nutrition of plant during the flowering time of rice. High dose of nitrogenous fertilizer during flowering aggravates the disease. Fujita et al. (1989) reported that RFS highly favoured by low temperature (15 °C) and higher humidity (100%) at the time of infection and relatively high temperature (25–35 °C) at later stage of colonization of the fungi. A lower maximum temperature, high humidity (>90%), moderate rainfall or drizzling condition and cloudy days and less sunshine during flowering period favoured the disease development (Muthuraman et al., 2007). The number of rainy days during flowering period have profound role in disease development and is more important compared to the amount of total rainfall (Laha et al., 2016). Rainfall period more than one week at booting and heading stage of rice influenced epidemiology of RFS (Hu et al., 2010). Long-term observation in the fields revealed that, the disease incidence will be serious when relatively low temperature (22-28˚C), and humid or rainy weather prevails more than five days consecutively during late booting to grain filling stages of the plant (Liu et al., 2009). but RFS disease incidence of the same rice variety in different years are quite different; if the susceptible varieties expose to dry and high temperature during the same stages, then RFS disease incidence will decrease or even no infection will be occurred (Wang et al., 2004). An experiment on staggered showing of six varieties (Pooja, Sarala, Durga, Anjali, Naveen and Geetanjali) suited for different ecosystem during 2018 and 2019 revealed that false smut appeared in most of the varieties when they are flowering during the month of September and October irrespective of their sowing dates. In the same experiment, it is observed that long duration varieties (Pooja, Sarala and Durga) are more prone to RFS infection than short/ mid-duration varieties (Anjali, Naveen and Geetanjali) might be due to exposure for longer time of favourable environment or might be due to resistant gene (s) being broken or the susceptible genes were recognised by the fungal effectors that enabling the growth and reproduction of the pathogen. Generally, rice plants flower mostly September to November in India which coincide with the favourable weather for growth of RFS pathogen. Therefore, varieties sown on 4th August 2018 and 24th May 2019, were found infected with false smut irrespective of their genotypes and sowing dates except Anjali (Baite et al., 2021) and these are in agreement with the findings of Fujita et al (1989). In eastern part of India false smut ball is found in ratoon of *kharif* rice and *rabi* (summer) rice during June-July when the ratoon and summer rice exposed to cool temperature and drizzling rain for longer period because of long spell of rainy weather duration during its late booting to milky stage (Bag et al., 2019). These *U. virens* off season smut ball is anotherprimary source of infection of RFS and these support in dissemination of inoculum to infect the crop grown on-season and this might be the reason of moderate to heavy incidence of the disease throughout the country.

3. Bakanae/ foolish seedling disease of rice

Bakanae, also called as foolish seedling disease, is one of the serious emerging problems of rice growing regions of India. The disease was believed to restrict in the basmati growing regions north-west and northern India (Bashyal et al., 2014), but in last few years its emerged as another major problem in non-basmati regions like Odisha, West Bengal, Bihar, Jharkhand and Assam (Raghu et al., 2018). The disease causes varied degree of losses in grain yield and quality depending upon the varieties grown, climatic conditions, season and stage of the crop growth (Ou, 1985). The losses may reach 100% under epidemic or outbreak conditions (Ou, 1985). In recent years, negligence in using seed dressing fungicides, lack of awareness in separating infected seeds from healthy seeds, development of resistance by the pathogen against commonly used fungicides are the common reasons for increase in disease incidence. As high as 70% yield reduction has been reported from several locations of the world (Hajra et al., 1994). 25% yield loss has been reported from Bangladesh (Hossain et al., 2007), 40% from Nepal (Desjardins et al., 2000), 20-50% from Japan (Kanjanasoon, 1965), whereas 3.7-14.7% loss was reported from Thailand (Ito and Kimura, 1931). In India, the disease can cause 15-20% yield losses under different conditions and the losses may reach even 100% under severe incidence (Sunder et al., 2014; Raghu et al., 2018). The disease though causes more damage to basmati cultivars, it can cause significant damage in yield and quality to non-basmati rice varieties also (Butt et al., 2011; Bashyal, 2018;).

3.1 History and distribution of the disease

The reason behind the interest of the scientist over these fungi was its capability to produce gibberellins and other growth regulators. Yabuta, Simuki and Hayashi in 1935 successfully isolated this growth regulating compound and this leads to the discovery of the industrial use of these fungi. The work on giberellin and other related compounds were carried out by Yabuta and his associates, later Mori and his associates worked on synthesis of gibberellin like substances. The disease was first described in India by Thomas (1933) who reported it as foot rot of rice. The presence of telemorphic stage in nature attracted Sun and Snyder (1978) and other researchers to carry out exclusive investigation on disease epidemiology, etiology and disease cycle in Taiwan. The disease was also reported from Turkey, Pakistan, Nepal, Bangladesh, Vietnam, Indonasia, Malaysia, Srilanka, Italy, China, Korea, Japan, Thailand, Phillippines, American countries, European countries and Africa (Matic et al., 2017).

3.2 Changes in Bakanae disease scenario in India

Bakanae, once a minor disease, is emerged as major problem under changing climatic scenario and cultivation practices. The disease is believed to be reported first from Japan since 1828 and later it was Hori (1898) who first described the disease,its symptoms and identified the causal organism as *Fusarium heterosporum* Nees. Later Fujikuro found that, the sexual stage of the fungus is *Lisea fujikuroi* and Sawada described the asexual stage of the fungus as *Fusarium moniliformae* Shield. Till 2000, there were no reports of severe incidence of bakanae disease in India except sporadic incidence in few places of Haryana. But few incidences of severe incidences were reported from Haryana and Punjab and mostly observed in basmati rice growing areas and later in parts of Telengana and Tamilnadu during 2001-14 (Laha et al., 2016). The disease has been reported in moderate to severe incidence from almost all rice growing states of India and recorded sporadic incidence from Andhra Pradesh, Bihar, Maharashtra, and Tripura (Sarkar, 1986).

3.3 Symptom

'Bakanae' is a Japanese word means 'bad', 'naughty' or foolish. Since the disease is capable of producing number of symptoms, thuscalled as foolish seedling in different locations and foot rot in other locations. The most common disease symptoms are yellowing and abnormal elongation/hypertrophy of the infected plants. The pathogen also causes rotting of the seedlings prior to germination and establishment, seedling blight, crown rot, etiolation of the plants, sterility or discoloration of the infected seeds, production of empty/chaffy panicles (Ou, 1985; Desjardins et al., 2000). Some other significant symptoms are browning of the internodes, production of adventitious roots on each node of the infected plants, white mycelia mass bearing conidia of the fungus inside the hollow internodes (Surek and Gumustekin, 1994). Sasaki (1973) reported about the appearance of lesion on rice leaves, but Sun (1975) reported that vegetative parts above the ground are not sites of infection. Sasaki (1976) also reported the presence of elongated ratoon plants in Japan. Rotting of the complete culm or few tillers in the plant, elongated/yellow seedlings, chaffy panicles were also reported (Bashyal et al., 2018). The development of different symptoms is mainly due to the production of growth hormones by the fungus. When the fungus produces excess gibberellic acid, the symptoms seen as abnormal elongation, pale green lanky seedlings, production of adventitious roots and chaffy grains. Similarly, when fungus produces fusaric acid, foot rot or death of the seedlings can be observed (Bashyal et al., 2018;).

3.4 Taxonomy and etiology of the causal organism

Bakanae disease is caused by a group of species belongs to genus *Fusarium*. However, the major species associated with bakanae is *Fusarium fujikuroi*

Nirenberg (Leslie and Summerell 2006). The anamorph of the fungus is *Fusarium moniliformae* Sheld. The perithecial stage of the *Fusarium moniliformae* Sheld was described by Sawada (1917) and reported as *Lisea fujikuroi*. Wineland (1924) described the name *Gibberella moniliformis* and proposed the name *Fusarium moniliformae* to the perithecial stage of the fungus. Some other species are *Fusarium proliferatum* (Mats.) Nirenberg and *Fusarium verticilloides* (Sacc) Nirenberg, thus forming a species complex named as *Fusarium fujikuroi* species complex-FFSC (*Gibberella fujikuroi* species complex-GFSC) (Amoah et al., 1995; Desjardins et al., 2000). The pathogen is a filamentous fungus belongs to Phylum Ascomycota of the kingdom Fungi. It belongs to Class Sordariomycetes, Order Hypocreales, Family Nectriaceae. The fungus produces ascus, the fruiting body bearing ascospores. The colony is white cottony with luxuriant growth with pink or yellow pigmentation when cultured on potato dextrose agar (PDA). As per Wollenweber and Reiking (1935), the perithecia of the fungi is dark blue, spherical to ovate, rough outside, 250-330 x 220-280 (190-390x 160-420) µm and asci are cylindrical piston-shaped, flattened above, 90-102x 7-9 (66-129 x 7-14) µm, 4-, 6-, seldon 8-spored, monostichous or indistinctly distichous; spores one-septate, about 15 x 5.2 µm (mostly 14-18 x 4.4-7µm), occasionally (in one spored asci) larger (27-45 x 6-7µm).The pathogen produces both microconidia and macroconidia but not chlamydospores. Macroconidia are 3-5 septate and microconidia are 0 -1 septate (Leslie and Summerell 2006). The *Fusarium fujikuroi* species complex is divided into 10 different mating populations (MP A-J) which are fully fertile and play major role in pathogenicity. But only three mating populations i.e., A (*Fusarium vertililloides),* C *(Fusarium fujikuroi),* and D *(Fusarium proliferatum)* are associated with bakanae disease of rice (Desjardins et al., 2000).

3.5 Disease cycle and epidemiology

Bakanae is highly seed-borne in nature and can transmit from seed to fresh healthy seeds. Hemmi et al., (1931) found that seeds are infected at the flowering stage. When severely infected, the kernel develops a reddish discoloration due to the presence of conidia of the pathogen and more often the whole seed become discolored. The fungus may be isolated even from seeds appear to be healthy, when collected from an infected field. On germination such seeds produce seedlings with bakanae symptoms, whereas the reddish-colored seeds produce stunted seedlings. Therefore, overgrowth or stunting may be determined by the degree of infection of seeds. Seto (1937) determined that spraying of spore suspension during flowering time is the most favourable stage for development of seed infection. Infection continues for upto three week thereafter occur at a reduced level. The fungus also infects the branches of the panicle.

100% of the rice seeds produced *F. moniliformae* on agar plates when collected from moderately infected fields and when sowed, 30% of them expressed bakanae symptoms. Ascospores oozed out from the ostioles when relative humidity was low and discharge either at night or during rain. 1 - 31.2% seedling found infected when seeds collected from apparently healthy-looking seeds in a diseased field

(Kanjanasoon, 1965). The abundant conidia and perithecia present in diseased culms at the time of flowering and maturation, enabling seed infection or contamination. He also reported that, wet seeds carry less pathogen than dry seeds. The best suitable temperature for disease development is between 27-30 ^{0}C and most suitable temperature is 35 ^{0}C. When the temperature is low, the disease incidence also reduces (Saremi and Farrokhi 2004). High nitrogenous fertilizer application significantly reduces disease incidence (Mandal and Chaudhuri, 1988). Saremi and Farrokhi (2004) observed that, in transplanted rice the disease pressure will be more compared to direct seeded rice.

The disease is also soil-borne (Seto, 1933a). 93% infection occurred when soils are inoculated immediately. But only 0.7% and no infection when inoculated after 90 180 days respectively (Kanjanasoon, 1965). This indicated non-survival of fungi in soil for longer duration in tropics. Rain water washes conidia and ascospores of diseased plants and stubble to the soil (Sun, 1975), thus rice soils are commonly contaminated with the fungi, and provide a reservoir for infection of seeds or seedlings. The fungi survive in soil in the form of thick-walled hyphae or macroconidia for about 4 months.

4. Sheath rot disease of rice

Sheath rot is another emerging and post-flowering fungal disease of rice. The disease is reported from almost all the rice growing areas of the world and particularly south east Asian countries. The disease appears to be a potential threat to rice production for its crop damaging nature and incurring substantial yield loss. Depending on the pathosystem conditions, yield losses range from 20 to 85 percent (Sakthivel,2001).

Rice sheath rot was originally assumed as localised disease. Since Asia's green revolution in the 1960s, rice farming practises have changed dramatically. Crop intensification, and introduction of semi-dwarf and photoperiod-insensitive cultivars induces rice crop to be susceptible to sheath rot complex disease (Bigirimana et al., 2015). This disease has been linked to a variety of infections, and cannot be determined on the basis of symptoms (Bigirimana et al. 2015). Presence of many sheath rot pathogens and unawarness about their infection process leads to develop resistant variety a tough task (Bigirimana 2016; Chauhan et al. 2017a; Mvuyekure et al. 2017). *Sarocladium oryzae*, a fungus, and *Pseudomonas fuscovaginae*, a bacterium, are the main pathogens connected to this syndrome. *Fusarium andiyazi*, *Fusarium proliferatum, Fusarium verticillioides,* and *Fusarium fujikuroi* also induce sheath rot symptoms (Bigirimana 2016; Wulff et al. 2010). Both *S. oryzae* and *P. fuscovaginae* are seed-borne as explained by their rapid spread (Adorada et al. 2015). The predominant secondary metabolites that reproduce sheath rot symptoms in the host plants are helvolic acid and cerulenin. On penetration of these acid into rice tissues cause electrolyte leakage and amount of electrolyte leakage is proportional to susceptibility of rice sheath rot (Sakthivel et al., 2002). Tschen et al. (1997) replicated *S. oryzae* symptoms on rice seedlings using a helvolic acid solution, including growth retardation and chlorosis. Helvolic acid, a tetracyclic triterpenoid, prevents chlorophyll production (Ayyadurai et al., 2005). Cerulenin, a hexaketide amide, prevents polyketide and fatty acid production by interfering with the malonyl-ACP: acylACP condensation process (Omura, 1976). Gopalakrishnan et al. (2010) found a significant drop in sugar, starch, and protein, as well as an increase in phenol content when rice seeds were infected with *S. oryzae*. This explains why contaminated grains are chaffy and do not germinate well.

Only *F. fujikuroi* strains can produce gibberellin A, and cause bakanae disease, in particular abnormal elongation of rice plants. The primary species that produce mycotoxins, such as fumonisin B have been associated to rice sheath rot (Wulff et al., 2010). Fumonisin-producing *F. verticilloides* strains are well-known and have been discovered in isolates from a variety of additional *Fusarium* species. The significance of fumonisins in *Fusarium* ecology and pathogenesis is not well recognised.

4.1 History and distribution of the disease

Sawada originally recorded signs of rice sheath rot and the pathogen *S. oryzae* in Taiwan during 1922. (Singh and Dodan 1995). *S. oryzae* has been reported to spread in many rice-producing countries, including Bangladesh, Cameroon, India, Korea, Japan, Peru, Philipines, Thailand, Venezuela, Vietnam, USA, Indonesia, Brunei Darussalam, China, Pakistan, Nepal, Malaysia, Saudi Arabia, Sri Lanka, Tajikistan, Uzbekistan, Burundi, Gambia, Cote d'Ivoire, Kenya, Madagaskar, Niger, Nigeria, Senegal. Rice sheath rot was initially discovered in Indonesia during the dry season of 1987 (May to August). According to observations, rice sheath rot (S. oryzae) has been identified in rice fields across Sumatera, Java, Bali, Lombok, South Kalimantan, and South Sulawesi.

4.2 Changes in sheath rot disease scenario in India

During the period of 1981-90, very few occurrences of severity of sheath rot disease were reported from Bihar and Punjab, whereas few sporadic incidences of low to moderate intensities were reported from Andhra Pradesh, Haryana, Himachal Pradesh, Karnataka, Odisha, Tamil Nadu, Uttar Pradesh and West Bengal. During 1991-2000, the disease became a serious problem in some parts of Bihar. High incidences were comparatively less but significantly increased in Andhra Pradesh, Telangana, Haryana, Karnataka, Maharashtra, Odisha, Tamil Nadu, Uttar Pradesh and West Bengal. However, during 2001-2014, the disease spread significantly in many areas of Andhra Pradesh, Bihar, Haryana, Gujarat, Odisha, Tamil Nadu, Uttar Pradesh and West Bengal. Geographical spread of the disease was also substantially increased in states like Jammu & Kashmir, Himachal Pradesh, Kerala, Maharashtra and Puducherry (Laha et al., 2016).

4.3 Symptom

The common symptom produced by *S. oryzae* begins with 0.5–1.5 cm long oblong or irregular spots with brown margins and grey centres; initial symptoms enlarge and coalesce, covering the leaf sheath; young panicles remain within the sheath or only partially emerge depending on the spread of the disease. Whitish powdery growth can be observed inside the affected sheaths, and young panicles are rotted. Infection with *S. oryzae* causes chaffy, discoloured grains, as well as a decrease in seed viability and nutritional content (Gopalakrishnan et al.,2010). *F. proliferatum* produces symptoms very fast at the lower leaf sheaths and may develop lesion of dull to dark brown initially and later off-white to tan with a reddish-brown border, then, that finally covers the whole sheath. Lesions also develop in lower leaf sheath and a dense white to pinkish powder made up of *F. proliferatum* microconidia and conidiophores, which is obviously visible during wet periods. Symptoms produced by *P. fuscovaginae* is distinguished by 2–5 mm wide, longitudinal brown to reddish brown necrosis, and extending the length of the leaf sheath and blade (Bigirimana et al., 2015).

4.4 Taxonomy and etiology of the causal organism

The first organism associated to rice sheath rot symptoms was *Sarocladium oryzae*, which was discovered in Taiwan in 1922 as *Acrocylindrium oryzae* (Mew and Gonzales, 2002). *Sarocladium* is a plant pathogen, saprobe, mycoparasite, endophyte, and probable human pathogen genus that was first reported by Gams and Hawksworth (1975). There are now 16 species in the genus *Sarocladium*, which include plant pathogens, saprobes, mycoparasites, endophytes.The Hypocreales order of the Phylum Ascomycota is home to the genus *Hypocrea*. It was long assumed that *S. attenuatum* was a different species that caused sheath rot, but it is synonymous of *S. oryzae*. Bills et al. (2004) discovered that *Cephalosporium caerulans,* is conspecific with *S.oryzae* (Bigirimana et al., 2015). *S.oryzae* produces mycelium that is whitish, sparingly branching, and septate. Each whorl of conidiophores has 3–4 phialades and is branched once or twice. The conidia are hyaline, aseptate, and cylindrical shape that can be seen on the phialades' tip. The conidia germinate and infect the plant through stomata, later, within vascular and mesophyll tissues, mycelium develops intercellularly (Hittalmani et al., 2016).

The *F. fujikuroi* complex largely follows Wollenweber and Reinking's (1935) Section Liseola, where four species (including *F. moniliforme* and *F. proliferatum*) were identified by Nelson et. al., (1983). *F. fujikuroi* complex, consist more than 50 species withthree clades of African, Asian, and American. The most important organisms react with rice are *F. verticillioides* from African clade and *F. proliferatum* and *F. fujikuroi* belong Asian clade (Bigirimana et al., 2015).

Pseudomonas, a Gram-negative bacterium belonging to the subclass Gammaproteobacteria, now has 144 species. *P. fuscovaginae*, like *P. asplenii*, is a member of the *P. asplenii* subgroup, according to Gomila et al (2015). *Pseudomnas fuscoaginae* cells, on the other hand, are rod-shaped with spherical ends, aerobic, gram-negative, non-spore-forming, and 0.5–0.8 2.0–3.5 m in length. Cells can be found alone or in pairs, and their motility is aided by one to four polar flagella.

4.5 Disease cycle and epidemiology

Seeds carry pathogens that cause sheath rot, resulting sick seedlings. Contaminated seedlings might die or live, leaving infected plant debris behind. *P. fuscovaginae* can live epiphytically and infect inflorescences during the booting stage, or it can colonise the entire plant as an endophyte. Conidia or bacterial cells discharged by infected plants cause secondary infections. Wind or rain distribute conidia, or bacterial cells, to healthy plants. Plants that are infected during the booting stage are particularly sensitive. The sheath that encases the newborn panicles rots, resulting in chaffy and discoloured grains on the damaged tillers. Pathogens spread to new areas by infected seed. Infected plant debris are act as primary source of inocula in the disease cycle (Bigirimana et al., 2015). *S. oryzae* is mainly found in low-lying areas, and thrives in hot, humid conditions (Pearce et. al., 2001; Sakthivel,2001). Sheath rot thrives in between 20^0 - 30^0 C temperatures and 65 - 85% relative humidity (Sakthivel, 2001). The fungi can infect plants at different stages; Insect and mite damage, as well as other illnesses that weaken the plant, facilitate *S. oryzae* penetration (Pearce et al., 2001). Secondary infections can spread through wounded tissues by the wind. Seed-borne disease transmission is less understood. *Fusarium* sp. is spread through seeds, and infected grains produce mycotoxins when they reach maturity (Wulff et al., 2010). *F. fujikuroi* was one of several microorganisms identified from rice seed surfaces; *F. fujikuroi* can survive 26 months in grains and 28 months in dry stubble. In fact, *F. proliferatum* could be recovered from the grains stored 6 months at 4–5°C. Survival is longer in normal circumstances. *P. fuscovaginae* is spread by seed, and infected seedlings. The lower section of the sheath turns brown, and the entire sheath eventually turns necrotic when infection happened late stage of tillering. *P. fuscovaginae* pathogenicity is expressed at the grain, seedling, and booting stages. *P. fuscovaginae* exist as an epiphyte until it infects the inflorescences and causes infection of grains or panicle abortion if the seedling survives.

5. Brown spot disease of rice

Brown spot of rice caused by *Bipolaris oryzae* (telemorph: *Cochliobolus miyabeanus*) first occurred in Japan in 1900. It has been reported from all major rice growing countries of the world namely China, Myanmar, Japan, Bangladesh, Philippines, Thailand etc (Khalili et al., 2012). Sundraraman first reported it from then Madras, India during 1919. The incidence of Brown spot is higher in direct seeded rice areas and in dry soils due to lack of water as found in the states of Bihar, Chhatisgarh, Jharkhand, Madhya Pradesh, Odisha and West Bengal. The disease frequently occurs in fields, deficient in water supply and nitrogenous fertilizers (Zadoks, 1974). Therefore, the disease is also well-known as poor farmer's disease (Zadoks 2002). The disease is important in many countries and has been reported to cause massive crop loss from 6 to 90% in Asia (Padmanabhan 1973; Mew and Gonzales 2002). The Great Bengal Famine in 1942 where approximately two million people died from starvation (Agrios, 2005) and a severe epidemic in Krishna-Godavari delta during 1918-19 (Baranwal et al., 2013) occurred owing to Brown spot of rice. The loss in grain yield varies with rice genotypes and time of occurrence (Kulkarni et al., 1980).

5.1 Changes in brown spot disease scenario in India

Brown spot is mainly a disease of *Kharif* (wet) season. The disease particularly occurs in environment where irrigation is limited and nutrient deficient soils (Baranwal et al., 2013). The disease was serious and occurred in severe form in Bihar, Uttarpradesh and Himachal Pradesh during 1981-90 whereas it appeared in low to moderate incidence in other parts of India. Severity and distribution pattern drastically changed during next decade (1990-2000). It gained important disease status in Haryana, Punjab and Madhya Pradesh whereas incidence reduced in UP and HP might be for improved package of practices. But there was dramatic increase in spread and incidence of the disease throughout India during 2001-14. It became major problem in states like Bihar, Jharkhand, Madhya Pradesh, Uttar Pradesh, Chhattisgarh and West Bengal and also in north Indian states like Jammu and Kashmir, Himachal Pradesh and Punjab and south Indian state of Tamil Nadu. Significant changes in climatic conditions like rainfall pattern and temperature and varietal changes might be the probable reasons for the increased level of incidence (Laha et al., 2016).

5.2 Symptoms

The pathogen, *Bipolaris oryzae* can attacks in all stages of rice plant. The symptoms appear on the leavesinitially as a small, circular, and dark brown spot. The leaves show typical spots that are brown in colour with grey or whitish centre, cylindrical or oval in shape. The symptoms are most noticeable on leaf blades and glumes. Several spots may coalesce eventually killing the leaf (Manandhar et al., 2016). The brown spot affected seedlings can be observed and recognised from a distance by scorched appearance of the seedlings (Sunder et al 2014).

5.3 Taxonomy and etiology of the causal organism

The pathogen causing brown spot of rice was first described by Breda de Haan as *Helminthosporium oryzae*.In 1900, Subramanian and Jain (1966) renamed it *Drechslera oryzae*. The fungus was then referred as *Bipolaris oryzae* by Shoemaker (1959) as the conidia germinated from two end cells. Ito and Kuribayashi (1927) termed as *Ophiobolus miyabeanus* after observing the teleomorph of the fungus in culture medium. Drechsler (1934) opined that the pathogen belonged to the genus *Cochliobolus* but Dastur (1942) officially reassigned it to that genus. Presently, the species name *Cochliobolus miyabeanus* (Ito and Kuribayashi, 1927) Drechsler ex Dastur is widely used and formally recognised as the teleomorph of *Bipolaris oryzae*.

In culture media, the fungus shows grey or black colour mycelial mass. The conidia are arranged with the oldest conidium towards base with 5-10 septations. Typically, the conidia are curved slightly and broadest at the centre (Ou, 1985).

5.4 Epidemiology and disease cycle

Conidia and mycelia of the pathogen thrive on seeds and crop residues might be the most common survival structures and primary source of inocula. The pathogen can infects all the plant part above the soil. Seedling stage is the most vulnerable that make the plants sick and accordingly reduce grain yield. Brown spot frequently affects plant whose soils are deficient in nutrients. The fungus can survive in soil and plant parts such as straw, stubbles and grains for about 3 years, which serve as primary sources of inocula (Ou, 1985). The primary infection generally comes from infected seeds (Damicone et al., 2001) while wind-borne inocula come from infected debris of rice straw, stubble etc. (Sato et al. 2008). Soil and some weed hosts also act as inoculum reservoirs (Biswas et al. 2008). The fungi enter the host through an infection peg originating from the appressoria (Ou, 1985). The inoculum of *B. oryzae* were observed all year round in air. However, the quantity of such infective inoculum was much higher during the cool days with high humidity (Kulkarni et al., 1982). There is also report that treatment with nitrogen fertilizer limited lesion expansion while application of silica decreased the number of brown spot lesions Ohata et al. (1972). Generally, appearance of the disease is very limited in the seasons of consistent rainfall (Singh et al. 2005) however seasons with infrequent and insufficient rainfall but heavy dew favour to form epidemic (Sherf et al. 1947). Drought has been recognized as most favourable situation for inducing brown spot epidemic. Water shortage enhances brown spot leading to more disease in rain-fed than in irrigated/flooded crop stands (Hegde et al. 1999;). Though temperature does not directly influence epidemic but temperature and humidity together induce infection efficiency (Percich et al. 1997). Decreasing daily minimum temperatures (9.3 to 7.5 C) lead to severity of the disease (Minnatullah and Sattar 2002). A complex interaction between water supply, available nutrients, soil characteristics play the role in variable brown spot incidence.

6. Conclusion

In spite of remarkable increases in rice production, warranting food security is a challenge with rapidly growing population and climate change. Analysis and investigations on climate change effect on plant diseases highlighted the effect of temperature than other weather parameters till date. Temperature changes directly affect the geographic distribution, spread and survival of pathogens in between the season. Increased temperature coupled with incessant rainfall induced huge changes of micro-climate and these are some major reasons of earlier minor diseases to be major at present days. Modification of strategies are essential to improve productivity. These emerging and re-emerging diseases are considered as new threats and seriously affect rice production. Researchers are studying intensively on details infection process, the molecular mechanisms of resistant genes to these diseases over decades, leading to some remarkable breakthroughs. Brown spot of rice, infect both seedling and adult plant, is relatively old disease yet relevant in present rice cultivation whenever favourable conditions prevail. Bakanae has the potential to cause 100% yield loss and quality deterioration and cause problem in both basmati and non-basmati rice varieties. Sheath rot and FSM are other two important diseases that have direct effect on grains vis-a-vis seeds.

All the diseases are difficult to manage once it establishes in field except brown spot. Thus, it is an urgent need to initiate more and more detailed investigations on host-pathogen relations, etiology and epidemiology of the causal organisms. Apart from this, searching for alternative management practices like biological control, plant based essential oils, elicitor compounds are needed. But importantly identification of new sources of resistance and utilizing them in resistant breeding program should be intensified. At last, multi-omics approaches should be adopted to understand deep insights into the pathogen-host relationship should be initiated.

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Chapter 19

Biological control in rice using *Trichogramma* spp. and *Habrobracon hebetor*: Implications of their quality

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Abstract

In agricultural and forest ecosystem where the exasperating behavior of the arthropod pests are now being tackled by bio-control agents. Of all bio-control agents, the most familiar and successful hymenopteran parasitoids, *Trichogramma* spp. and *Habrobracon hebetor* are the puissant weapons for the biological management of intractable pests. Generally, *Trichogramma* and *H. hebetor* are mass-reared on different factitious hosts over many generations for innundative field release. The successful performance of these parasitoids in the field greatly depends on their consistent quality maintenance in the laboratory during its various phases of mass-production, thereby affecting the whole success of field suppression. The quality of these bio-agents comprises of both host and parasitoid components. Substantial data has been generated for rearing requirements of the parasitoids and their factitious hosts, including reproductive biology, their storability, deterioration of cultures due to continuous laboratory rearing, etc. All these factors have a definite bearing on the production efficiency and the quality of the reared bio-agents. High-quality parasitoids are always preferred for innundative release. Selection guiding traits for high quality are sex ratio, fecundity, emergence, adult longevity, target specificity, searching behavior. All these are ecologically sensitive when parasitoids are released inundatively in the field. Living organisms are always subjected to variability starting from insectaries where they are mass-reared to the crop on which they are released. Hence this study approaches the retrospective quality and fitness of *Trichogramma* and *H. hebetor* useful for biological management of insect pests.

Keywords: *Trichogramma*, *Habrobracon hebetor*, biological control, factitious host, innundative release

1. Introduction:

The growing demand for food has always been associated with the constant threat of pests in agriculture. Although several pest management methods have been implicated with chemical management being the top priority, the insect pests continued to remain intractable and even became impossible to throw out of the window (Gowda et al. 2021a). In fact the fatuous behavior of farmers in using the chemical methods for managing insect pests has resulted in various ecological problems such as secondary pest outbreaks, pest resistance and resurgence, natural enemy's destruction (Wang et al. 2012) along with costing the quality of the crops and health of the living organisms. Rice which is the staple crop for a large number of people has also fallen into the vicious circle of chemical management. Hence, it's high time there is a need for a Panglossian approach *i.e*. use of biological methods to manage insect pests without having a risk to the ecology and human health.

Globally, the augmentative biological control which supplements the population of natural enemies is being produced from time to time and more than 150 species are made available commercially in a large arena in various cropping systems. It is a significant method for decreasing the usage of pesticides (Van Lenteren and Bueno 2003). Augmentation is largely applied in the open field as well as greenhouses, where the whole spectrum of inexorable pests is decreased by the bio-agents (Van Lenteren 2000b). Among the natural enemies, hymenopteran parasitoids played a crucial role in curbing the inexorable pests. Among all, the most commonly used natural enemy of crop pests is the egg parasitoid *Trichogramma* and larval parasitoid *Habrobracon hebetor*.

The hymenopteran genus *Trichogramma* consist of wasps which are apparently the most prevailing mass-cultured and released parasitoids of insects and this is all in view of the fact that they are able to parasitize a broad range of Lepidopteran pest eggs such as yellow stem borer, rice leaf folder (Wang et al. 2014). Around the world, to date, there are more than 200 known species of *Trichogramma* but the number of species that can be mass-reared, released is only 19 (Li 1994).

The larval parasitoids belonging to the Braconidae family are prominent specifically the larval parasitoid *H. hebetor*. *H. hebetor* being an idiobiont and gregarious ecto larval parasitoid has been brought from Varamin, Iran for the first time and is used for successful management of pests (Kyoung et al. 2008). The augmentative release of the ectoparasitoid has become a promising strategy in managing several species of moth caterpillars such as the larval stage of Indian meal moth *Plodia interpunctella*, the late larval stage of the Mediterranean flour moth *Ephestia kuehniella*, almond moth *Cadra cautella*, dried fruit moth *C. calidella* and also *Helicoverpa armigera* and millet head miner *Heliocheilus albipunctella* (Altuntas et al. 2010).

Globally using these wasps for defenestrating the intensively damaging pests is due to their competency and for having a simple rearing process under laboratory conditions (Parra and Zucchi 1997). Better knowledge about the ecological needs, host requirements, morphological features and physiological fitness can harbor tremendous success for the wasps. All these are ecologically sensitive when parasitoids are released innundatively in the field. Living organisms are always subjected to variability starting from insectaries where they are mass-reared to the crop on which they are released. It has also been established that continuous rearing of parasitoids under artificial laboratory conditions could alter several behavioral traits including the host searching behavior which is a primary parameter (Geden et al. 1992). The achievement of using *Trichogramma* and *H. hebetor* in biological control greatly relies on recognition of the supreme host species, along with better know-how of the ecological needs of the parasitoid (Van Lenteren et al. 1997). The quality of a host is mainly determined by its essential trait i.e. size and age of the chosen host species (El-Wakeil 2007). The guideline which dictates the important criterion in quality control are mainly longevity, fecundity, efficacy, adult emergence, and sex ratio and nutrition which plays a crucial role in these parameters (Coelho et al. 2016; Gowda et al. 2021b). There is an urgency to establish measurable indicators or parameters that can very well assess the quality of parasitoids accurately and standardize and validate those internationally. Unfortunately, in recent days the field of biological pest management has had a dearth of quality control measures being taken during the mass multiplication which has led the graph of success to a decline. (Van Lenteren et al. 2003). Hence this current study approaches the retrospective quality and fitness of *Trichogramma* and *H. hebetor* with a complete comprehensive up-to-date synthesis of the various quality parameters which govern success in fields.

2. Quality Control: Ancient Adages

For ages the literature on quality control of mass-produced arthropods has been revealing numerous exemplariness of the poor performance of natural enemies and is because of the fact that the quality control measures were not been taken strictly as they should be. More over facts regarding the menial natural enemies' disastrous result in failing the bio-control programme is very familiar but the scriptures hardly spoke about it in their publications. This text of giving an urge to ask what is leading to bio-control failure, why quality control should be kept on the topmost priority list before any mass multiplication, and how it should be done was brought into notice by Bigler (1994). During the 1980s Soviet Union presented some publications regarding quality control on *Trichogramma*. A modification in the mass rearing network and maintenance of the colony has ameliorated the strain performance along with an increase in the limit of efficiency by at least 75% parasitization in the field. This has led to the production of a new unit because the important aspects of quality are negatively affected during the rearing procedure. The combination of the traits can predict the overall performance more than a single trait. The superiority of the natural enemy in the field is a good indicator of the rearing quality.

It is well-known fact that *Trichogramma* are 'ephemeral' hence there was an impoverishment in the production system which changed previously from a 'short period production with a high daily output' to a 'long period production with a low daily output'. The advancement in long-term storage of the parasitoids has lengthened the period of mass production. Such change in quality control parameters has been circumvented to achieve success in bio-control. The continuous performance experiments carried out in the laboratories have helped in gaining the idea about the mistakes leading to the deterioration of the efficiency and thus initiating ways to rectify those lacunas. This research is the sole key to the success of a sophisticated quality control establishment (Bigler 1994).

For more than 30 years some producers have taken the initiative of indulging quality control parameters in the rearing techniques of mites and other beneficial insects but it has gained success during the past 10 years and all because of the alliance between researchers and the bio-control industry which demarcated the development of 30 harmonized quality control guidelines (Van Lenteren et al. 2003).

A population with characteristics like higher fecundity, sex ratio (female biased), emergence, adult longevity, host-searching behavior, and tolerance to local weather situations etc are considered as superior quality. These traits have ecological significance when parasitoids are released innundatively. In terms of innoculative releases, parameters like oogenesis, development rate and competitive ability is mandatory (Smith 1996). Interestingly, few attributes that make the parasitoid effective in the field may be more difficult or impossible to mass rear in laboratory. Hence, trade-off needs to be worked out for the desired traits before considering them as quality parameter.

3. Factors affecting the quality control:

3.1 Morphology of the host

The achievement of using *Trichogramma* and *H. hebetor* in bio control greatly relies on recognition of the supreme host species, along with a better understanding of the ecological needs of the parasitoid. The size, age, and species of the host are all important biotic parameters that influence parasitoids' progeny fitness. (Temerak 1984). The quality of the host has an impact on key aspects of parasitoid fitness, such as egg to adult survival, parasitoid growth time, parasitoid size, and adult fecundity. Large hosts, in general, have more resources and are thought to be qualitatively superior in terms of parasitoid fitness (Godfray 1994).

3.1.1 Size of the host

It is mandatory to use a laboratory host instead of a natural host on a large. The hosts which are familiar for rearing hymenopteran parasitoids are namely Mediterranean flour moth, *Ephestia kuehniella* or *Anagasta kuehniella* (Zeller); rice moth, *Corcyra cephalonica* (Stainton); and the Angoumois grain moth, *Sitotroga cerealella* Olivier (Nagaraja 2013). Behind the proclamation of the use of the possible factitious host depends on its effortlessness rearing process and cost procured instead of the components in relation to the development of wasps produced (Greenberg et al. 1998b). Often certain qualities such as development time, travel speed, longevity, percent emergence and sex ratio have been seen to be affected. (Bai et al.1995). Among the various measures host size is of utmost importance since the size of the wasp that emerged could be alternated depending on the host size.

In examining the sensitivity and detoxification process of *H. hebetor* venom, host species and size are extremely important. Larger larvae, such as noctuids, usually require more venom to paralyze them since the venom may not be efficient in suppressing the larger-bodied host following parasitism and may be depleted quickly (Khalil et al.2016). The oviposition behavior of *H. hebetor* is also influenced by the size of the host. It has been discovered that *H. hebetor* prefers to deposit eggs on giant larvae rather than smaller ones (Xie et al.1989). For example, on *P. interpunctella* larvae, female *H. hebetor* laid more than 7-12 eggs per host every day (Yu et al. 2003). It has been discovered that *H. hebetor* prefers to deposit eggs on giant larvae rather than smaller ones (Xie et al.1989).

In terms of *Trichogramma* it is very evident that the host rearing techniques can bring a size variation in the wasps emerged such as *T. carverae* reared on *E. postvittana* eggs are significantly larger than those reared on *S. cerealella* and a similar size orientation is seen in the adult females of *T. pretiosum* and *T. minutum* which prove the fact that the host eggs on which the egg parasitoids are being reared is an essential part of quality control (Greenberg et al. 1998c). Fitness of the parasitoids wasps is largely in association with the size and direct relationship exists among the two. An increase size is directly associated with the parasitoids fitness used as a measure in hosts locating. (Bennett and Hoffmann 1998).

3.1.2 Host age

Apart from the size of the host, the age of the host is also important. Various outcomes in terms of host quality have been recorded. *H. armigera* late instar larvae (fourth to sixth instars) are best suited for parasitism and development of *H. hebetor* (Saxena et al.2012). The rate of parasitoid development is usually higher in older host larvae, possibly because larger hosts have more ample resources to support parasitoid development (Harvey et al. 2000). In comparison to third instar larvae, the later instar larvae (fourth to sixth instars) produce more cocoons, have a higher adult emergence rate, and have a longer adult lifespan(Saxena et al.2012).

In the case of the egg parasitoids, the host egg consists of nutritional reserves such as protein, lipid and glycogen concentrations and all of these vary with the host age and thereby affecting adult life cycle features predominantly its size, wing loading, longevity and fecundity. The nutritional reserves are present in higher amounts in high-quality eggs which in turn mark a significant offspring production and intensify mobilization. The amount of protein and triglycerides are significantly more in one-day-old eggs thereby demarcating the development of host quality and wasp's fitness. A greater fecundity and longevity was seen in one-day-old eggs whereas the wing loading index is reduced in *Trichogramma*. The proportion of female offspring is also at the top. For oviposition, *Trichogramma* favor one-day-old eggs of *Maruca vitrata* whereas for feeding they go for 2- 3 day old eggs. There is no parasitism in 3-day old eggs of *M. vitrata* (Farahani et al. 2016). Therefore the one-day-old hosts are considered superior age behind the wasp's production along with fitness since it consists the highest amount of protein, glycogen and triglyceride.

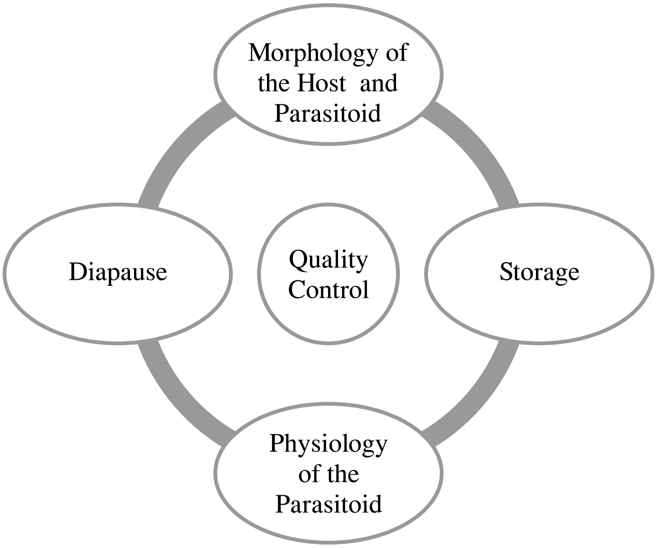

Figure 1. Pillars of Quality Control

3.1.3 Quality of the diet for host

Adult parasitoids, such as *H. hebetor*, need supplementary food sources such as sugars and other carbohydrates to extend their life span. The parasitoid's reproductive success is heavily influenced by the host's nutrition. Variability in host nutrition amount and quality is expected to have a big impact on a lot of parasitoid fitness factors (Jervis et al. 2008; Gowda et al. 2021c). *H. hebetor*, as a synovigenic parasitoid, may gain certain nutrients required for reproduction during larval feeding (Eslampour and Aramideh 2016). The effects of different honey, sugar, and date syrup solutions on the longevity, fertility, and female emergence of *H. hebetor* are substantial. Parasitoids fed a 50 percent honey solution lived longer and laid a greater number of eggs than those fed other solutions. This is most likely owing to the honey's sugar and water content (Barbehenn et al.1999). Longevity, lifetime, fecundity, host searching efficiency, and total activity can all be influenced by carbohydrate-rich food or hosts (Eliopoulos et al. 2003).

It is already proclaimed that for the best quality host there should be a superior quality diet since it imprints its significance in modifying the egg quality content and thus becomes integral in developing egg parasitoid indirectly. Cereals such as sorghum, wheat, and corn fed to the laboratory host predominantly induce the development and egg production of variable sizes by the host and thus affecting the parasitism and sex ratio of the wasps which are reared on the eggs of the host (Krishnamoorthy, 2012). Fecundity and egg size were largely affected in different diets. The moths reared on corn, wheat and barley resulted in larger eggs along with a higher parasitism and adult emergence of the *Trichogramma* parasitoid (Hamed and Nadeem, 2012). Similarly the emergence percentage of the adults on the eggs of factitious host *C. Cephalonica* reared on millet was high than the sorghum.

3.2 Morphology of the parasitoid

Numerous proxies determine the fitness of the *Trichogramma* and *H. hebetor* namely size, longevity, fecundity, mating ability and vagility. Each of these proxies is associated positively with the lifelong fitness gained by an individual. Still, the plasticity of the phenotypes (i.e. a genotypes' ability to give rise to definite phenotypes based on environmental conditions) is efficient enough to change these proxies' value.

3.2.1 Size of the parasitoids

Although the body size of the parasitoid is not directly related, size plays a pivotal role in indexing fitness. Size is the most evident effect of phenotypic plasticity in *Trichogramma*. In a similar fashion as that of the quality of the food on which hosts are reared, parasitoids too depend on the host species' quality i.e. age and size which determine their life-history traits. These traits may be tibia length, ovipositor length etc like in *T. euproctidis* (Girault), females when emerged singly from *Plutella xylostella* (L.), resulted in a tibia length of 115 µm but this length of tibia increases upto 196 µm when reared on *Trichoplusia ni* (Hubner) eggs. In a few cases, *Trichogramma* size and specifically the length of the ovipositor relies on the host as well as the number of parasitoids per host. The length of the ovipositor is longer in *T. evanescens* than in T. *pretiosum* and *T. exiguum*, but in all the 3 species the width is the same. The necessity of the ovipositor size is important because it has an impact on the possibility of laying eggs in vitro in artificial host eggs. This possibility is hampered when the ovipositor is short or narrow since the eggs are made of inappreciable membrane thickness (Grenier et al. 2001) Wing loading is also incorporated within the body size. The females' wing loading characteristic also poses as the best indicator for their capacity to fly, where lower wing loads result in dispersal capacities in a better way (Vuarin et al. 2012).

3.2.2 Age of the parasitoids

The parasitoid age has a significant impact on fecundity. Offspring's production is reduced as the female grew older. Because older females lay fewer eggs than younger females, the decline in fertility over the course of a female's lifetime is physiologically age-dependent (Gul and Gulel 1995). The age of the female parasitoids has a big impact on the sex ratio. Wasps produce slightly female-biased progeny on all hosts after oviposition by 3-week-old females, and then gradually transition to male-biased progeny after oviposition by >4-week-old females (Ghimire and Philips 2014).

3.3 Physiology of the parasitoid

The quality controls criteria of the adult parasitoid are well explained from the life history traits of the parasitoids which explain the physiology of the hymenopterans' parasitoid.

3.3.1 Longevity

It is said that more the life span of an organism more it has a period for conquering the world. In a similar fashion, the long life span of *H. hebetor* and *Trichogramma* helps in conquering different patches of the host. The parasitoids having a longer life expectancy can strive even in the harshest conditions and thus can search for the hosts (Fatouros et al. 2008). The dearth of food hampers the longevity of an individual. When proper food is unavailable the females of *Trichogramma* can live for 2-3 days whereas an ample amount of food helps them to survive for more than 6 days.

3.3.2 Fecundity

Fecundity is the predominant aspect of the female hymenopteran. *H. hebetor* is a synovigenic parasitoid producing yolk-rich (anhydropic) eggs. Several egg parasitoid species have the tendency to oviposit their entire egg load in a singular host egg mass and thus any reduction in fecundity will hamper its fitness. The Ovigeny index is the best way to explain the temporary distribution of investment in female reproduction. At emergence, the proportion of fecundity is the highest and thus it is the best proxy of fitness for the parasitoids. (Jervis et al. 2001).

3.3.3 Parasitism

Parasitism is in fact, one of the major criteria since the ability to parasitize the notorious pest is greatly exploited in IPM. The parasitism rate of an adult greatly varies from one host to the other. The parasitism rate of *Trichogramma* greatly varies from one host to the other. The rate of parasitism of the adults was highest on *S. cerealella* which were reared from the latter. In a similar fashion when adults were reared from *S. cerealella* and *E. kuhniella* and tested on *O. nubilalis* then the rate of parasitism decreased in comparison to the adults reared from the *O. nubilalis*.

3.3.4 Sex ratio

The parasitoid's sex ratio must be understood in order to execute an effective mass-rearing method (Hentz et al. 1998). Females regulating egg fertilization influence the sex ratio of progeny in haplodiploid hymenopteran parasitoids (Jarosik et al. 2003). Host density affects the sex ratio of the *H. hebetor*. The egg-laying potential of each female parasitoid increases with the increase in host density which results in more male progeny as compared to females. An increase in temperature resulted in a significant increase in sex ratio. The progeny sex ratio was female-biased at lower temperature variants in comparison to high-temperature levels (Singh et al. 2014).

3.4. Diapause

Diapause is a fascinating question in the biology of development and allows a better understanding of local adaptation and phenotypic plasticity to seasonal variations in the environment in insects. A major physiological adaptation is constituted by both diapauses and quiescence to strive during extreme catastrophic situations and both have practical implications during rearing in mass in storage. (Chang et al. 1996). Exploiting diapauses for future prospects is challenging specifically in terms of mass rearing and cold storage. It is tedious to employ diapauses for storage purposes since the mortality rate is very high under artificial environments. (Colinet and Boivin 2011). Despite these strains, the embankment of achievement is raising with flying colors. The natural enemies are being able to store in cold conditioning for numerous weeks before their release in mass and with the advantage of no impairments in fitness. (Hun et al. 2004). Thus, the focus should be given to improving different storage methods to produce bio-control agents efficiently while having a balanced cost of production. The diapauses benefitted the hymenopteran wasp *T. dendrolimi* in context with the quality for storing in cold conditions for long period along with efficient parasitism on Asian corn borer at the time of mass release. (Zhang et al. 2018). The diapauses are also affected by the *Wolbachia*. It affects the diapauses and energy reserves of *T. brassicae in* response to light wavelengths. Photoperiod has a maternal effect on diapause induction in *Trichogramma* wasps (Kaldeh et al. 2019).

3.5 Storage

An ample amount of natural enemies are being used in today's bio-control programmes. High market demands during the season time pose a challenge for the insectaries for a parallel production rate. This drawback can be easily overcome by constructing a favorable storage protocol. Entomophagous insects shelf life can be increased if stored at low temperatures for a certain specified time. This proves as a clear-cut advantage to avail an adequate number of insects at proper weather conditions for releasing it in the fields also to provide it to the concerned farmers during high demanding periods. It provides flexibility and also smoothens the efficiency to produce in mass, to help to get a desired stage of development for peak release. (Leopold 1998).

Storage of H. *hebetor* pupae at 6ºC for 3 weeks resulted in an 82.7% decrease in adult emergence (Al-Tememi and Ashfaq 2005). The storage duration of *H. hebetor* pupae also has tremendous effects on the survival of pupa, the emergence of adults, parasitism percentage, female and male longevity, female fecundity and sex ratio. (Mansour 2017).*T. evanescens* and *T. oleae* reared on *E. kuehniella* is seen to have an emergence rate of 60% when stored at 4 °C for 21 days (Gharbi 2014). The pupal stage of T. *chilonis* and *T. achaeae* reared on factitious host *C. cephalonica* (Stainton) eggs can meet the demands by storing at 4 °C for 2 weeks and 8 °C for 4 weeks and having an adult emergence rate of 70% (Singhamuni et al. 2015). The adult emergence of *T. nerudi* is not affected if stored at 5 °C for up to 50 days provided having acclimatization of 20 days at 12 °C.

4. Conclusion:

Every kith and kin of *Trichogramma* and *H. hebetor* mass rearing are associated with the quality control parameters. The quality control guidelines have paved a way for establishing long-term biocontrol technologies involving coordination between the central and local governments, engagement of the science community, and support from society. The new research in the field of *Wolbachia* has already marked its efficiency in improving the mass rearing and long-term storage of parasitoids. Further, the exploitation of this quality control guideline could help in improving the efficiency of the other natural enemies and thus playing a crucial role in integrated pest management.

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Chapter 20

Screening, Identification and Cataloguing of Rice Genotypes for Resistance to Major Pests and Diseases

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Abstract

Rice, primary staple food of Asia, is spread in countries beyond the boundary of the Asian continent. World rice production has increased significantly but the growth rate in yields is not increased significantly. Therefore, rice researchers are facing a herculean task of improving rice productivity because of the constraints like reducing cultivable land and limiting water and change in climate. All these factors have brought changes in the pest and disease scenario also. Many insects and pathogens infect rice to survive in nature and do not cause problems in production and productivity but many of them now became major and most emerging diseases and pests of rice. Crop protection is one of the important factors for sustaining high productivity and production. As the major activity of crop protection, screening and identification of resistant sources of germplasm are necessary to co-operate the breeders in developing resistant varieties. Screening for resistant genetic resources should be continuous as the insects and pathogens are also changing their genetic makeup for their existence in the changing climatic situation. Cataloguing of identified resistant sources as well as status of disease and pest reaction of the screened germplasm is useful for future uses.

Keywords: Rice, germplasm, landraces, disease, pest, SES scale

1. Introduction

Upto 70% increase in agricultural production is needed to fulfill the food requirements for a steadily growing population. Rice (*Oryza sativa* L.) is one of the imperative food crops and is the staple food crop of about half of the global population. The crop is being cultivated in almost all the countries in diverse ecologies. But, rising pest and diseases are major hindrances to attaining the targeted food production. Pests and pathogens cause up to 37% of rice yield loss on average. The easiest way of managing rice pest and diseases through the use of pesticides effect adversely on the agro-ecosystem. Based on the information generated from All India Coordinated Project on Rice (1965 to 2017), at present number of major rice insect pests are 20 and major rice diseases are 10 in India. Among the major insect of rice, yellow stem borer (YSB) *Scirpophaga incertulas* (Lepidoptera: Crambidae), is one of the most important insect in different rice ecosystems and rice leaf folder, *Cnaphalocrocis medinalis* (Guenée) (Pyralidae: Lepidoptera), another important emerging insect of rice in many Asian countries. Apart from this there are many minor pests which are acquiring the major pest status under changing climatic scenario.

The use of resistant/tolerant rice varieties, particularly in endemic areas, is the most suitable solution to pest and disease management. But development and deployment of resistant/tolerant rice varieties are not easy tasks. The search has begun for new resistant donors to different pests from the existing plant genetic resources (PGR) of the country including those identified in the past. The PGR may be landraces and primitive cultures, farmers' varieties, varieties released recently or many years back, parent genotypes used to develop hybrids, genetic stocks with desirable traits, and wild and weedy cultures. These are valuable sources for future breeding work to develop varieties with multiple traits. They can be utilized to develop resistant varieties against pest and diseases, abiotic stresses like drought, salinity, submergence, high temperature, yield-related traits etc. The resistant donors can be identified through standard screening of many genotypes and later confirmed through the study of resistance mechanism. Besides marker-assisted breeding, new technologies like CRISPR/Cas9, RNAi are now available for developing resistant/tolerant varieties. ICAR-National Rice Research Institute (NRRI), Cuttack, Odisha is the premier and pioneer institute in rice research. The institute has got a very old history of more than 75 years for its dedication to rice research. The institute not only develops resistant varieties against various biotic and abiotic stress and agronomic traits but also conserved more than 40000 rice accessions in its gene bank till now. This huge collection is available for the researchers to utilize and evaluate for various desirable traits. Crop Protection Division is screening the rice germplasm (such as Odisha rice collection, Sikkim & Manipur, Tripura, Assam, Farmers varieties, North Indian collection) against major pests like brown planthopper, green leafhopper, white baked planthopper, gall midge, stem borer, stored grains, leaf folder etc., the diseases like blast, brown spot, sheath blight, false smut, sheath rot, bacterial blight, bakanae, are being evaluated under both controlled and field condition. The identified sources of resistance are further evaluated through the development of NILs/RILs to develop resistant cultivars. The standard evaluation system (SES) provided by the International Rice Research Institute (IRRI), Philippines is being followed for screening and cataloguing of the rice germplasm against these biotic stresses. Detailed screening protocols, scoring scale and the identified resistant line are provided in the following paragraphs. Cataloguing all rice genotypes evaluated for knowing the reaction status against major and most emerging diseases and pests as well as finding the resistant donors is a herculean task. Thus, emphasis has been given on cataloguing the reaction status of rice landraces and NRRI released varieties to major and most emerging diseases and pests.

2. Importance of cataloguing

Host Plant Resistance (HPR) plays a very significant role in insect and disease management. This is the backbone of integrated pest management (IPM) to increase production and productivity to meet ever-growing population of world (Godfray et al., 2010). Resistant crops can provide an effective and economical way for the management of insect pest and diseases. Understanding the genetic diversity of insect pest and pathogen population requires continuous effort in introducing new resistance gene/QTL sources against a virulent biotype. The important consideration for the effective utility and longevity of host plant resistance is the knowledge of the nature and degree of variability of genotypes in pest/pathogen populations. Wild species possess important sources of HPR genes/QTLs to insect pest and diseases which have a considerable amount of resistance. Few recent studies have shown that some wild relatives have genetic components that provide genetic gains in terms of improved agronomic performance along with pest resistance. In general, six generations are required to transfer the pest/pathogen-resistant traits from source to high-yielding cultivars in traditional breeding approaches. But molecular marker technology had reduced the time and space of resistance breeding. Difficulties in the transfer of traits from wild sources are greatly solved by using molecular markers. Near isogenic lines (NILs), recombinant inbred lines (RILs), F2 and backcross populations, double haploids can be used in gene mapping programs in rice. Numerous techniques have been developed and successfully employed over the past decade to characterize genetic diversity in a population, detect DNA sequence polymorphism, genome sequencing and fingerprinting, locating genes/QTLs on a chromosome, fine mapping, population genetics studies, diagnostics and plant breeding. Different types of molecular markers deployed to construct high-density genetic linkage maps for rice.

3. Screening methodology for identifying resistant genotypes to different insect pests of rice and cataloguing

3.1 Brown Planthopper (BPH)

The brown planthoppers would be reared in susceptible rice variety TN1. Uniform 40-50 days old non-infested potted plants were kept inside the oviposition cages and BPH population with 1:1 adult male and female ratio were released inside the cage to get BPH culture. Plants are transported 24 hours exposure to adult insects to new rearing cages and oviposition date is labelled. Then these insects are taken for screening. The rice germplasm to be screened are evaluated for BPH resistance with standard seed box technique. The seed box is another method in which rice genotypes are screened. In brief, seeds of respective cultivars (generally 20 cultivars/ box) are seeded in a single row including ideal susceptible and resistant checks in similar rows in a seed box (60 × 40 × 10 cm). After 10 days of sowing, seedlings are being thinned to 20-25 plants per row and each seedling is allowed to infest with eight second instar nymphs. When susceptible check TN1 had become completely wilted in the seed box, the tests were terminated, and the seedlings of tested genotypes are scored as per Table 1 (Horgan, 2015). The tests will be repeated for another season in a greenhouse to confirm the results.

Table 1. Evaluation standard for rice resistance to planthoppers based on seedling mortality

Score	Rice damage	Resistance level
0	No damage	Immune
1	Slight damage to a few plants within a row	Highly resistant
3	First and second leaves of each plant partially yellowing	Resistant
5	Pronounced yellowing or stunting of plants, or 10–25% of plants wilted within a row	Moderately resistant
7	More than 50% of plants wilted or dead and the remaining plants severely stunted or dying	Moderately susceptible
9	All plants wilted or dead	Susceptible

Source: Standard Evaluation System for rice (SES), IRRI, Manila, Philippines, 2002 & Horgan et al., 2015.

3.2 Gall midge

Seeds of the desired plant materials are soaked in water for 24 hours in small petri dishes. Usually, 30 seeds are used for a full line of sowing in a plastic tray (60 x 30 x 30cm). Three days after soaking, germinated seeds are sown in plastic trays containing leveled and puddle fertilizer enriched soil in the tray with 2mm deep 13 furrow lines are drawn with a wooden stick. With the help of forceps, the germinated seeds of the test plants are placed in the ten furrow lines leaving the two borders and one central line. Two border lines adjacent to the tray edges are used for sowing TN1 seeds to serve as susceptible check to monitor pest pressure and validity of the test. The middle line is used to sow an appropriate differential host plant resistant check. Ten days after sowing, plants with three leaf stage are used for insect infestation by placing the tray in a cage made of nylon mesh. Newly emerged 30 numbers of mixed adults collected from the rearing cages with the help of an aspirator are released on two consecutive days to obtain high level of infestation. Date of release of insect is noted and recorded on the plastic label placed in the tray. On third day, trays are transferred to the high humidity chambers. On fifth day trays are brought back to growth chamber and maintained at room temperature. After a period of about ten days from release of insects, susceptible plants show initial symptoms of infestation in the form of swelling at the base of the stem. Later the final symptoms in the shape of galls or silver shoots appear after 20 days of insect release. When most of the plants in the susceptible check line show symptoms of protruded galls the test entries are scored for plant damage as per Table 2. This includes counting of total plants and damaged (susceptible) plants (Bentur et al., 2011). Observations on silver shoot formation will be taken when 90% of TN1 seedlings will show silver shoot symptoms.

$$\text{Percentage of plant damage} = \frac{\text{No. of plants with silver shoots}}{\text{No. of total plants}} \text{ X } 100$$

Table 2. Plant damage scoring due to gall midge

Damage (Plants with Silver Shoot)	Score	Status
No damage	0	Highly resistant
<5%	1	Resistant
6-10%	3	Moderately resistant
11-20%	5	Moderately susceptible
21-50%	7	Susceptible
>50%	9	Highly susceptible

Source: Bentur et al., 2011

3.3 Stem borers

Thirty days old healthy seedlings are transplanted in Randomized Block Design, with three replications, to evaluate germplasm against stem borers. Single seedling was transplanted per hill. with spacing of 15×15 cm. Incidence of stem borer in terms of dead heart is recorded 30 days after transplanting (DAT) and white ear head at 75 and 95 DAT. Ten plants per culture are selected randomly for recording the damage data like dead heart (%) and white ear (%) and was calculated using the following formulae and scored as per SES Scale for Rice, IRRI, 2002 (Table 3).

$$\text{White ear \%} = \frac{\text{number of white ears}}{\text{number of productive tillers}} \text{ X } 100$$

$$\text{Dead heart \%} = \frac{\text{number of damaged shoots}}{\text{total (healthy + damaged) shoots}} \text{ X } 100$$

Table 3: Scoring for stem borer damage

Score	Dead heart (%)	White ears (%)	Status
0	No damage	No damage	Highly resistant
1	1-10%	1-5%	Resistant
3	11-20%	6-10%	Moderately resistant
5	21-30%	11-15%	Moderately susceptible
7	31-60%	16-25%	Susceptible
9	61% & above	26% & above	Highly susceptible

Source: Standard Evaluation System for rice (SES), IRRI, Manila, Philippines, 2002

3.4 Leaf folder

Screening of rice genotypes against leaf folder was carried out under field and net house condition as per the method suggested by Standard Evaluation System for Rice, IRRI, 2002. In field transplanting of 20 seedlings for each variety was done in two lines at 25x10 cm spacing. One resistance check TKM-6 and Susceptible check TN1 was also be included in the middle after 10 genotypes. About two rows of susceptible check TN1 should be transplanted surrounding the main field. At 25 days after transplanting (DAT) cover the genotypes with nylon net and leaf folder adults were released inside the net. Adults were released 2 times once at 40 DAT and then at 60 DAT@ 100 adults per release. Cotton dipped in 20% honey solution was placed inside the net as source of food for adults. Remove the nylon net after a week and observations were recorded at 05 randomly selected hills per entry after 30 DAT and at 15 days' interval. At each observation, total number of leaves and leaf folder damaged leaves were recorded to calculate percent damage in each genotype. The per cent damaged leaves were converted to adjust damage area rating (ADAR) using the following formula, which was then converted to 0 to 9 scale (Table-4).

$$\text{Damaged leaves (\%)} = \frac{\text{Number of damaged leaves in a hill/plant}}{\text{Total number of leaves observed in a hill/plant}} \text{ X } 100$$

$$\text{Adjusted damaged area rating (\% ADAR)} = \frac{\text{\% damaged area in test entry}}{\text{\% damaged area in susceptible check}} \text{ X } 100$$

Table 4. Scoring for leaf folder damage

Scale	Rating	ADAR
0	Resistant	No damage
1		1 to 20%
3		21 to 40%
5	Moderately Resistant	41 to 60%
7	Susceptible	61 to 80%
9		More than 80%

Source: Standard Evaluation System for rice (SES), IRRI, Manila, Philippines, 2002

3.5 Nematodes

About 15 days old seedlings are inoculated with the second stage juveniles (J_2) of rice root knot nematode, *Meloidogyne graminicola* at the rate of 1 J_2 / g soil. The plants are uprooted 30 days after nematode inoculation and the roots were washed in tap water. Then the roots are stained with acid fuchsin dye (3.5 g Acid fuchsin, 250 ml Glacial acetic acid and 750 ml Distilled water) and destained with lactophenol solution (100 ml lactic acid, 100 g Phenol, 200 ml Glycerol, and 100 ml Distilled water) to count the number of galls per root system under microscope. Based on the gall index score (Table 5) of Bhatti and Jain (1994), the reaction of the plants towards the nematodes was assessed.

Table 5. Gall index score (Bhatti and Jain, 1994):

Gall index	Galls/ root system	Reaction
1	0	Highly Resistant
2	1-10	Resistant
3	10.1-30	Moderately Resistant
4	30.1 – 100	Susceptible
5	>100	Highly Susceptible

Source: Bhatti and Jain, 1994

Lists of NRRI varieties and land races showing different reaction to insect pests are given in Table 6. A list of NRRI varieties resistant to multiple biotic stresses are also given in Table 7.

Table 6. Response of different rice varieties against major insect pests

Brown Planthopper (BPH)	
Resistant	Lalat, IR-64, Improved Tapaswini, Khandagiri, Luna Suvarna.
Moderately Resistant	Rajlaxmi, Ajay, Chandrama, Chandan, CR Dhan 305, Phalguni
Susceptible	Padma, Bala, Kiron, Krishna, Ratna, Vijaya, Saket-4, Jayanti, Kalinga-I, Kalinga-II, Shakti, Supriya, Vani, Naikichili, Anamika, Indira, Pallavi, Ramakrishna, Samalei, Sattari, Narendra-1, Savitri/ Ponmani, Khitish, CR 138-928, Kalinga-III, Utkalprabha, Annada, CR 1014, Dharitri, Gayatri, Heera, Kalashree, Kalyani-II, Moti, Padmini, Panidhan, Tulasi, Vanaprabha, Shaktiman, CR 1002, Lunishree, Seema, Sneha, Vandana, Radhi, Sonamani, Tapaswini, Pooja, Sarala, Durga, Shatabdi, Anjali, Hazaridhan, Sadabahar, Abhishek, Virender, Geetanjali, Ketekijoha, Naveen, Varshadhan, Nuakalajeera (Aromatic), NuaDhusara (CR Sugandh Dhan 3), Hanseswari (CR Dhan 70), CR Dhan 40, Swarna Sub1, Sahbhagi Dhan, Reeta (CR Dhan 401), NuaChinikamini, CR Dhan 501, CR Dhan 701, CR Dhan 601, CR Dhan 500, Satyabhama (CR Dhan 100), Pyari (CR Dhan 200), Hue (CR Dhan 301), Sumit (CR Dhan 404), Poorna Bhog (CR Dhan 902), Jalamani (CR Dhan 503), Jayanti Dhan (CR Dhan 502), Luna Barial (CR Dhan 406), Luna Sankhi (CR Dhan 405), CR Dhan 907, CR Dhan 300, CR Dhan 303, CR Dhan 304, CR Dhan 201, CR Dhan 202, CR Dhan 407, CR Dhan 505, CR Dhan 204, CR Dhan 306 (IET 22084), CR Dhan 205 (IET 22737), CR Dhan 101 (Ankit), CR Dhan 203 (Sachala), CR Dhan 206 (Gopinath), CR Dhan 307 (Maudamani), CR Dhan 408 (Chaka Akhi), CR Dhan 310, CR Dhan 207 (Srimati), CR Dhan 209 (Priya), CR Dhan 409 (Pradhan Dhan), CR Dhan 507 (Prasant), CR Dhan 800, CR Sugandh Dhan 910 (Aromatic), CR Dhan 311 (Mukul), CR Dhan 508, CR Dhan 506, CR Sugandh Dhan 908 (Aromatic), CR Sugandh Dhan 909, (Aromatic), GangavatiAgeti (Aromatic), Purna, CR Dhan 309, CR Dhan 801, CR Dhan 510, CR Dhan 511, CR Dhan 312, CR Dhan 313, CR Dhan 602, Santha Bhima (CR Dhan 102), Sarumina (CR Dhan 210), CR Dhan 410 (Mahamani), CR Dhan 308, CR Dhan 314, CR Dhan 315, CR Dhan 318, CR Dhan 316, CR Dhan 411, CR Dhan 412, CR Dhan 512, CR Dhan 702, CR Dhan 703.
Gall midge (GM)	
Resistant	Lalat, Shaktiman, IR-64, Geetanjali, CR Dhan 301, Improved Lalat, CR Sgandh Dhan 907, CR Dhan 304, Phalguni
Moderately Resistant	Ajay, Abhishek, Chandrama, Satyakrishna, CR Dhan 307 (Maudamani), CR Dhan 311, Pyari (CR Dhan 200), CR Dhan 207 (Srimati) Khandagiri, Udayagiri, Anjali, atyabhama (CR Dhan 100), Ketekijoha, CR Dhan 500, Jalamani, Gayatri
Susceptible	Padma, Bala, Kiron, Krishna, Ratna, Vijaya, Saket-4, Jayanti, Kalinga-I, Kalinga-II, Supriya, Vani, Naikichili, Anamika,

	Indira, Pallavi, Sattari, Narendra-1, Savitri/ Ponmani, Khitish, CR 138-928, Kalinga-III, Utkalprabha, Annada, CR 1014, Kalyani-II, Moti, Padmini, Panidhan, Tulasi, Vanaprabha, CR 1002, Lunishree, Seema, Sneha, Vandana, Radhi, Sonamani, Tapaswini, Pooja, Sarala, Durga, Shatabdi, Sadabahar, Virender, Naveen, Rajalaxmi (Hybrid), Varshadhan, Nuakalajeera (Aromatic), Chandan (CR Borodhan 2), Hanseswari (CR Dhan 70), Swarna Sub1, Sahbhagi Dhan, Reeta (CR Dhan 401), Luna Suvarna (CR Dhan 403), Luna Sampad (CR Dhan 402), CR Dhan 501, CR Dhan 701, CR Dhan 601, Improved Tapaswini, Sumit (CR Dhan 404), Jayanti Dhan (CR Dhan 502), Luna Barial (CR Dhan 406), Luna Sankhi (CR Dhan 405), CR Dhan 300, CR Dhan 303, CR Dhan 305, CR Dhan 201, CR Dhan 202, CR Dhan 407, CR Dhan 505, CR Dhan 204, CR Dhan 306 (IET 22084), CR Dhan 205 (IET 22737), CR Dhan 101 (Ankit), CR Dhan 203 (Sachala), CR Dhan 206 (Gopinath), CR Dhan 408 (Chaka Akhi), CR Dhan 310, CR Dhan 209 (Priya), CR Dhan 409 (Pradhan Dhan), CR Dhan 507 (Prasant), CR Dhan 800, CR Sugandh Dhan 910 (Aromatic), CR Dhan 508, CR Dhan 506, CR Sugandh Dhan 908 (Aromatic), CR Sugandh Dhan 909, (Aromatic), Purna, CR Dhan 309, CR Dhan 801, CR Dhan 802 (Subhas), CR Dhan 510, CR Dhan 511, CR Dhan 312, CR Dhan 602, Santha Bhima (CR Dhan 102), Sarumina (CR Dhan 210), CR Dhan 410 (Mahamani), CR Dhan 308, CR Dhan 314, CR Dhan 315, CR Dhan 319, CR Dhan 320, CR Dhan 316, CR Dhan 317, CR Dhan 411, CR Dhan 412, CR Dhan 413, CR Dhan 512, CR Dhan 803.
Green Leafhopper (GLH)	
Resistant	Lalat, Shaktiman, IR-64
Moderately Resistant	CR Dhan 601 CR Dhan 207 (Srimati), Parijat, Phalguni, CR Dhan 101 (Ankit), CR 1002, Jalamani
Susceptible	Padma, Bala, Kiron, Krishna, Ratna, Vijaya, Jayanti, Kalinga-I, Kalinga-II, Supriya, Vani, Naikichili, Indira, Pallavi, Ramakrishna, Samalei, Sattari, Narendra-1, Savitri/ Ponmani, Khitish, CR 138-928, Kalinga-III, Utkalprabha, Neela, Sarasa, Annada, CR 1014, Dharitri, Gayatri, Heera, Kalashree, Kalyani-II, Kshira, Padmini, Panidhan, Tulasi, Vanaprabha, Lunishree, Seema, Sneha, Vandana, DhalaHeera, Radhi, Sonamani, Tapaswini, Pooja, Sarala, Durga, Shatabdi, Anjali, Hazaridhan, Sadabahar, Abhishek, Chandrama, Virender, Geetanjali, Ketekijoha, Naveen, Rajalaxmi (Hybrid), Ajay (Hybrid), Varshadhan, Satya Krishna (CR Dhan 10), Nuakalajeera (Aromatic), NuaDhusara (CR Sugandh Dhan 3), Chandan (CR Borodhan 2), Hanseswari (CR Dhan 70), CR Dhan 40, Swarna Sub1, Sahbhagi Dhan, Reeta (CR Dhan 401), Luna Sampad (CR Dhan 402), NuaChinikamini,

	CR Dhan 501, CR Dhan 701, CR Dhan 500, Satyabhama (CR Dhan 100), Pyari (CR Dhan 200), Hue (CR Dhan 301), Improved Tapaswini, Sumit (CR Dhan 404), Poorna Bhog (CR Dhan 902), Jayanti Dhan (CR Dhan 502), Luna Barial (CR Dhan 406), Luna Sankhi (CR Dhan 405), CR Dhan 907, CR Dhan 300, CR Dhan 303, CR Dhan 305, CR Dhan 304, CR Dhan 201, CR Dhan 202, CR Dhan 407, CR Dhan 505, CR Dhan 204, CR Dhan 306 (IET 22084), CR Dhan 205 (IET 22737), CR Dhan 203 (Sachala), CR Dhan 206 (Gopinath), CR Dhan 408 (Chaka Akhi), CR Dhan 310, CR Dhan 409 (Pradhan Dhan), CR Dhan 507 (Prasant), CR Dhan 800, CR Sugandh Dhan 910 (Aromatic), CR Dhan 311 (Mukul), CR Dhan 508, CR Dhan 506, CR Sugandh Dhan 908 (Aromatic), CR Sugandh Dhan 909, (Aromatic), GangavatiAgeti (Aromatic), Purna, CR Dhan 309, CR Dhan 801, CR Dhan 510, CR Dhan 511, CR Dhan 312, CR Dhan 313, CR Dhan 602, Santha Bhima (CR Dhan 102), CR Dhan 410 (Mahamani), CR Dhan 308, CR Dhan 314, CR Dhan 315, CR Dhan 318, CR Dhan 320, CR Dhan 316, CR Dhan 317, CR Dhan 411, CR Dhan 412, CR Dhan 413, CR Dhan 512, CR Dhan 702, CR Dhan 703, CR Dhan 803.
Leaf folder	
Resistant	CR Dhan 300, Satyabhama (CR Dhan 100), CR Dhan 500, Luna Suvarna
Moderately Resistant	Pratikshya, CR Dhan 601, CR Dhan 306, CR Dhan 307 (Maudamani) Pyari (CR Dhan 200), CR Dhan 202, CR Dhan 205, CR Dhan 203, CR Dhan 206, CR Dhan 207 (Srimati), CR Dhan 209 (Priya), Anjali, Sahbhagidhan, CR Dhan 101 (Ankit) Ranidhan, Jalamani, CR Dhan 505, CR Dhan 408 (Chaka Akhi), CR Dhan 409 (Pradhan Dhan), CR Dhan 507 (Prasant) CR Dhan 506, CR Dhan 510, Luna Barial
Susceptible	Padma, Bala, Kiron, Krishna, Ratna, Vijaya, Saket-4, Jayanti, Kalinga-I, Kalinga-II, Shakti, Supriya, Vani, Naikichili, Anamika, Pallavi, Ramakrishna, Samalei, Sattari, Narendra-1, Savitri/Ponmani, Khitish, CR 138-928, Kalinga-III, Utkalprabha, Neela, Sarasa, Udaya, Annada, CR 1014, Dharitri, Gayatri, Heera, Kalashree, Kalyani-II, Kshira, Moti, Padmini, Tara, Tulasi, Vanaprabha, CR 1002, Lunishree, Seema, Sneha, Vandana, DhalaHeera, Radhi, Sonamani, Tapaswini, Pooja, Sarala, Durga, Shatabdi, Hazaridhan, Sadabahar, Abhishek, Chandrama, Virender, Geetanjali, Ketekijoha, Naveen, Rajalaxmi (Hybrid), Ajay (Hybrid), Varshadhan, Satya Krishna (CR Dhan 10), Nuakalajeera (Aromatic), NuaDhusara (CR Sugandh Dhan 3), Chandan (CR Borodhan 2), Hanseswari (CR Dhan 70), Swarna Sub1, NuaChinikamini, CR Dhan 501, CR Dhan 701, Hue (CR Dhan 301), Improved Lalat, Improved Tapaswini, Poorna Bhog

	(CR Dhan 902), Jayanti Dhan (CR Dhan 502), Luna Sankhi (CR Dhan 405), CR Dhan 907, CR Dhan 303, CR Dhan 305, CR Dhan 304, CR Dhan 407, CR Dhan 310, CR Dhan 800, CR Dhan 311 (Mukul), CR Dhan 508, CR Dhan 309, CR Dhan 312, CR Dhan 602, CR Dhan 411, CR Dhan 512, CR Dhan 702, CR Dhan 703
Pink Stem Borer (PSB)	
Moderately Resistant	Lalat, Improved Lalat, CR Dhan 306, CR Dhan 205 Parijat, Khandagiri, Udayagiri, Ketekijoha, Jalamani, CR Dhan 505 CR Dhan 506, CR Dhan 510
Susceptible	Padma, Bala, Kiron, Krishna, Ratna, Vijaya, Saket-4, Jayanti, Kalinga-I, Kalinga-II, Shakti, Supriya, Vani, Naikichili, Anamika, Indira, Pallavi, Ramakrishna, Samalei, Sattari, Narendra-1, Savitri/ Ponmani, Khitish, CR 138-928, Kalinga-III, Utkalprabha, Neela, Sarasa, Udaya, Annada, CR 1014, Dharitri, Gayatri, Heera, Kalashree, Kalyani-II, Kshira, Moti, Padmini, Panidhan, Tara, Tulasi, Vanaprabha, Shaktiman, CR 1002, Lunishree, Seema, Sneha, Vandana, DhalaHeera, Radhi, Sonamani, Tapaswini, Pooja, Sarala, Durga, Shatabdi, Anjali, Hazaridhan, Sadabahar, Abhishek, Chandrama, Virender, Geetanjali, Naveen, Rajalaxmi (Hybrid), Ajay (Hybrid), Varshadhan, Satya Krishna (CR Dhan 10), NuaDhusara (CR Sugandh Dhan 3), Chandan (CR Borodhan 2), Hanseswari (CR Dhan 70), CR Dhan 40, Swarna Sub1, Sahbhagi Dhan, Phalguni, Luna Suvarna (CR Dhan 403), Luna Sampad (CR Dhan 402), NuaChinikamini, CR Dhan 501, CR Dhan 701, CR Dhan 601, CR Dhan 500, Satyabhama (CR Dhan 100), Pyari (CR Dhan 200), Hue (CR Dhan 301), Improved Tapaswini, Sumit (CR Dhan 404), Poorna Bhog (CR Dhan 902), Jayanti Dhan (CR Dhan 502), Luna Barial (CR Dhan 406), Luna Sankhi (CR Dhan 405), CR Dhan 907, CR Dhan 300, CR Dhan 303, CR Dhan 305, CR Dhan 304, CR Dhan 201, CR Dhan 202, CR Dhan 407, CR Dhan 204, CR Dhan 101 (Ankit), CR Dhan 203 (Sachala), CR Dhan 206 (Gopinath), CR Dhan 307 (Maudamani), CR Dhan 408 (Chaka Akhi), CR Dhan 310, CR Dhan 207 (Srimati), CR Dhan 209 (Priya), CR Dhan 409 (Pradhan Dhan), CR Dhan 507 (Prasant), CR Dhan 800, CR Sugandh Dhan 910 (Aromatic), CR Dhan 311 (Mukul), CR Dhan 508, CR Sugandh Dhan 908 (Aromatic), GangavatiAgeti (Aromatic), Purna, CR Dhan 309, CR Dhan 801, CR Dhan 802 (Subhas), CR Dhan 511, CR Dhan 312, CR Dhan 313, CR Dhan 602, Santha Bhima (CR Dhan 102), CR Dhan 210, CR Dhan 410 (Mahamani), CR Dhan 308, CR Dhan 314, CR Dhan 315, CR Dhan 318, CR Dhan 319, CR Dhan 320, CR Dhan 316, CR Dhan 317, CR Dhan 411, CR Dhan 412, CR Dhan 413, CR Dhan 512, CR Dhan 702, CR Dhan 703, CR Dhan 803.

Yellow Stem Borer (YSB)	
Resistant	Improved Tapaswini
Moderately Resistant	Phalguni
Susceptible	Padma, Kiron, Jayanti, Kalinga-I, Kalinga-II, Shakti, Vani, Naikichili, Pallavi, Ramakrishna, Samalei, Sattari, Narendra-1, Savitri/ Ponmani, Khitish, CR 138-928, Kalinga-III, Utkalprabha, Neela, Sarasa, Udaya, CR 1014, Gayatri, Heera, Kalashree, Kalyani-II, Kshira, Moti, Padmini, Panidhan, Tara, Tulasi, Vanaprabha, Shaktiman, CR 1002, Lunishree, Seema, Sneha, Vandana, DhalaHeera, Radhi, Sonamani, Tapaswini, Pooja, Sarala, Durga, Shatabdi, Hazaridhan, Abhishek, Virender, Geetanjali, Naveen, Varshadhan, NuaDhusara (CR Sugandh Dhan 3), Hanseswari (CR Dhan 70), Swarna Sub1, CR Dhan 501, CR Dhan 701, Satyabhama (CR Dhan 100), Hue (CR Dhan 301), Luna Barial (CR Dhan 406), CR Dhan 303, CR Dhan 305, CR Dhan 304, CR Dhan 407, CR Dhan 310, CR Dhan 800, CR Dhan 508, CR Dhan 506, CR Dhan 510, CR Dhan 312, CR Dhan 317, CR Dhan 702, CR Dhan 703.
White Backed Planthopper (WBPH)	
Resistant	IR-64, Hazaridhan, Improved Tapaswini, Kalyani 2, Salivahan, Himadhan, Vandana, Kishira, Gajapati, Udaya, Saktiman, Amulya, Narendra1, Satabdi, Kalinga 1, Sarasa, Anjali, Phalguna, Krishnabeni
Moderately Resistant	Tapaswini, Ajay, Pratikshya, Chandrama, CR Dhan 305, CR Dhan 306, CR Dhan 307 (Maudamani) CR Dhan 209 (Priya), Khandagiri, Anjali, Phalguni, Satyabhama (CR Dhan 100), CR Dhan 408 (Chaka Akhi), Pusa sugandh-2, Banskathi, Padmini, Haryana Basmati, Virendra, Satyakrishna

Susceptible	Padma, Bala, Kiron, Krishna, Ratna, Vijaya, Saket-4, Jayanti, Kalinga-II, Shakti, Supriya, Vani, Naikichili, Anamika, Indira, Pallavi, Ramakrishna, Samalei, Sattari, Savitri/ Ponmani, Khitish, CR 138-928, Kalinga-III, Utkalprabha, Annada, CR 1014, Dharitri, Gayatri, Heera, Kalashree, Moti, Panidhan, Tara, Tulasi, Vanaprabha, CR 1002, Lunishree, Seema, Sneha, DhalaHeera, Radhi, Sonamani, Pooja, Sarala, Durga, Sadabahar, Geetanjali, Ketekijoha, Naveen, Rajalaxmi (Hybrid), Varshadhan, Nuakalajeera (Aromatic), NuaDhusara (CR Sugandh Dhan 3), Chandan (CR Borodhan 2), Hanseswari (CR Dhan 70), Swarna Sub1, Sahbhagi Dhan, Reeta (CR Dhan 401), Luna Suvarna (CR Dhan 403), Luna Sampad (CR Dhan 402), NuaChinikamini, CR Dhan 501, CR Dhan 701, CR Dhan 601, CR Dhan 500, Pyari (CR Dhan 200), Hue (CR Dhan 301), Improved Lalat, Sumit (CR Dhan 404), Poorna Bhog (CR Dhan 902), Jalamani (CR Dhan 503), Jayanti Dhan (CR Dhan 502), Luna Barial (CR Dhan 406), Luna Sankhi (CR Dhan 405), CR Dhan 907, CR Dhan 300, CR Dhan 304, CR Dhan 201, CR Dhan 202, CR Dhan 407, CR Dhan 505, CR Dhan 204, CR Dhan 205 (IET 22737), CR Dhan 101 (Ankit), CR Dhan 203 (Sachala), CR Dhan 206 (Gopinath), CR Dhan 310, CR Dhan 207 (Srimati), CR Dhan 409 (Pradhan Dhan), CR Dhan 507 (Prasant), CR Dhan 800, CR Dhan 311 (Mukul), CR Dhan 508, CR Dhan 506, CR Sugandh Dhan 908 (Aromatic), GangavatiAgeti (Aromatic), Purna, CR Dhan 801, CR Dhan 312, Santha Bhima (CR Dhan 102), Sarumina (CR Dhan 210), CR Dhan 410 (Mahamani), CR Dhan 308, CR Dhan 314, CR Dhan 315, CR Dhan 318, CR Dhan 320, CR Dhan 411, CR Dhan 412, CR Dhan 512, CR Dhan 702, CR Dhan 703.
Whorl maggot	
Moderately Resistant	Khandagiri, CR Dhan 506
Susceptible	Padma, Bala, Kiron, Krishna, Ratna, Vijaya, Saket-4, Jayanti, Kalinga-I, Kalinga-II, Shakti, Supriya, Vani, Naikichili, Anamika, Indira, Pallavi, Ramakrishna, Samalei, Sattari, Narendra-1, Savitri/ Ponmani, Khitish, CR 138-928, Kalinga-III, Utkalprabha, Neela, Sarasa, Udaya, Annada, CR 1014, Dharitri, Gayatri, Heera, Kalashree, Kalyani-II, Kshira, Moti, Padmini, Panidhan, Tara, Tulasi, Vanaprabha, Shaktiman, CR 1002, Lunishree, Seema, Sneha, Vandana, Radhi, Sonamani, Tapaswini, Pooja, Sarala, Durga, Shatabdi, Anjali, Hazaridhan, Sadabahar, Abhishek, Chandrama, Virender, Geetanjali, Ketekijoha, Naveen, Rajalaxmi (Hybrid), Ajay (Hybrid), Varshadhan, Nuakalajeera (Aromatic), NuaDhusara (CR Sugandh Dhan 3), Chandan (CR Borodhan 2), Hanseswari (CR Dhan 70), CR Dhan 40, Swarna Sub1, Sahbhagi Dhan, Phalguni, Reeta (CR Dhan 401),

	Luna Suvarna (CR Dhan 403), Luna Sampad (CR Dhan 402), NuaChinikamini, CR Dhan 501, CR Dhan 701, CR Dhan 601, CR Dhan 500, Pyari (CR Dhan 200), Hue (CR Dhan 301), Improved Lalat, Improved Tapaswini, Sumit (CR Dhan 404), Poorna Bhog (CR Dhan 902), Jalamani (CR Dhan 503), Jayanti Dhan (CR Dhan 502), Luna Barial (CR Dhan 406), Luna Sankhi (CR Dhan 405), CR Dhan 907, CR Dhan 300, CR Dhan 303, CR Dhan 305, CR Dhan 304,, CR Dhan 407, CR Dhan 306 (IET 22084), CR Dhan 205 (IET 22737), CR Dhan 101 (Ankit), CR Dhan 203 (Sachala), CR Dhan 206 (Gopinath), CR Dhan 307 (Maudamani), CR Dhan 408 (Chaka Akhi), CR Dhan 310, CR Dhan 207 (Srimati), CR Dhan 209 (Priya), CR Dhan 409 (Pradhan Dhan), CR Dhan 800, CR Sugandh Dhan 910 (Aromatic), CR Dhan 311 (Mukul), CR Dhan 508, CR Sugandh Dhan 908 (Aromatic), CR Sugandh Dhan 909, (Aromatic), GangavatiAgeti (Aromatic), Purna, CR Dhan 801, CR Dhan 802 (Subhas), CR Dhan 510, CR Dhan 511, CR Dhan 312, CR Dhan 313, CR Dhan 602, Sarumina (CR Dhan 210), CR Dhan 410 (Mahamani), CR Dhan 314, CR Dhan 315, CR Dhan 320, CR Dhan 316, CR Dhan 317, CR Dhan 411, CR Dhan 412, CR Dhan 413, CR Dhan 702, CR Dhan 703, CR Dhan 803.
Root knot nematode	
Moderately Resistant	ADT 14, ARC 5158, Basumati 370, IET 4786 IR 38, Jhona 20, Kalinga 1, Khanish, Lal danger, Laxman Sali, Manhar, MTU 15, Palghar 1, PTB 21, Pusa169, TKM 6, Zeera, Nigeria 5, IR-72, Basmata, Basmati 12-21, Kali lohiji, Padar bank

Source: Pathak et al., 2019; NRRI database https://icar-nrri.in/database-of-nrri/

4. Screening methodology for identifying resistant genotypes to different diseases of rice and catalogue of rice genotypes

4.1 Blast (*Magnoporthe oryzae*)

Rice blast reported as major constraint of rice production and the disease appeared in around 85 countries globally. 23 states of India have rice blast endemic districts and as a result those areas encounter different level of losses (Prasad et al., 2011; Turaidar et al., 2018). Leaf blast emerged as serious constraint for rice production during 2001-2014 in the states of Uttar Pradesh, Tamil Nadu, Chhattisgarh and Jharkhand (Laha et al., 2009).

4.1.1 Screening germplasm for rice blast

Collect the blast infected leaf samples from susceptible cultivar. The standard tissue isolation should be followed for isolation of *Magnoportheoryzae.* Follow, spore drop method as described by Rajashekara et al. (2017). To iosolate the pathogen, Potato Dextrose Agar (PDA) or Oat Meal Agar (OMA) serves the best purpose. The plates should be incubated at 28±1 °C. Morphological identification can be confirmed by the characteristics like hyaline conidia which are pyriform to oblong biseptate and 19 - 27 X 8 - 10 µm in size.

4.2 Preparation of inoculum

Spores from 10-day old culture preserved in plate or slant can be used for artificial inoculation. Remove the mycelium with as little agar as possible from the plates and prepare spore suspension by homogenising in a waring blender for 2-3 minutes. The spore concentration of the suspension can be checked with the help of low power of the microscope and necessary dilutions can be made to adjust the spore concentration at 5-10 spores per microscopic field, Shis concentration measured at X 150, amounts to 50,000 - 100,000 conidia per millilitre of suspension approximately (Goto, 1955).

High humidity should be upheld during night in the net house to assure disease development. The inoculated plants were checked at 7, 14 and 21 days after inoculation (DAI). For scoring following 0-9 SES scale of IRRI, 2013(Table 7) is used.

Table 7. Scale for scoring of rice leaf blast disease (IRRI SES scale, 2013)

Scale	Disease severity	Host Response
0	Lesion are not present	Resistant (R)
1	Small brown specks of pin point size or larger brown specks without sporulating center	Resistant (R)
2	Small roundish to slightly elongated, necrotic gray spots, about 1-2 mm in diameter, with a distinct brown margin. Lesions are mostly found on the lower leaves	Resistant (R)
3	Lesions type is same as in scale 2, but a significant number of lesions on upper leaf area	Resistant (R)
4	Typical susceptible blast lesions, 3 mm or longer infecting less than 4 % of leaf area	Moderately Resistant (MR)
5	Typical susceptible blast lesions infecting 4-10% of the leaf area	Moderately Resistant (MR)
6	Typical susceptible blast lesions infecting 11 – 25% of the leaf area	Moderately Susceptible (S)
7	Typical susceptible blast lesions infecting 26 - 50% of the leaf area	Susceptible (S)
8	Typical susceptible blast lesions infecting 51- 75% of the leaf area and many leaves are dead	Susceptible (S)
9	More than 75% leaf area affected	Susceptible (S)

4. 2. Sheath blight (*Rhizoctonia solani*)

Sheath blight disease of rice is another major disease and caused considerable yield losses (Sudhakar et al., 1998). introduction of high yielding, fertilizer responsive cultivars and changes in cultivation process indulges heavy sheath blight disease incidence and severity in rice-producing areas around the world (Groth et al., 1991).

4.2.1 Rhizoctonia solani Culture preparation and Maintenance

The pathogen can be isolated from infected stem by following standard tissue technique. Potato dextrose agar serves the best purpose to obtain pure culture of the pathogen. Once, pure culture is obtained, that can be preserved for long term storage. This culture can be used for artificial inoculation and screening of germplasm.

4.2.2 Rhizoctonia solani Inoculum Preparation

Mycelia or sclerotia of *R. solani* can be subcultured on potato dextrose agar (PDA) and grow at 28±1 °C). After 3-days, these cultures can be used to prepare mycelial plugs.

4.2.3 Method of inoculation

Rice plants can be inoculated by placing *R. solani* mycelial plugs inside the leaf sheath at maximum tillering stage and 80–100% humidity should be ensured. Plants can grow in ~30– 32° C in standard nethouse/greenhouse conditions.

Percentage disease intensity was calculated using the following formula:

$$\text{Disease intensity \%} = \frac{\text{Sum of all numerical ratings}}{\text{No. of plants observed} \times \text{Maximum rating}} \text{ X } 100$$

Table 8. Scale for scoring sheath blight disease (IRRI SES scale, 2013)

Scale	**Disease severity**	**Host Response**
0	No changes	Highly Resistant (HR)
1	Lesions limited to below 1/4 of the leaf	Resistant (R)
3	Lesions limited to below 1/2 of the leaves	Moderately Resistant (R)
5	Lesions present in more than 1/2 of the leaves	Moderately susceptible (MS)
7	Lesions present in more than 1/4 of the leaf surface. Severe infection in upper leaves (2 branches of withered leaves)	Susceptible (S)
9	Lesions reach the tiller. Severe infection on all leaves and some plants were killed.	Highly Susceptible (HS)

4.3 Brown spot (*Bipolaris oryzae*)

Brown spot of rice, caused by *Bipolaris oryzae* (syn. *Dreschslera oryzae*, *Helminthosporium oryzae*) is re-emerging disease of rice and a new threat for yield decline. Average 10% yield loss is reported across South and Southeast Asia (Savary *et al.* 2005). The pathogen infects almost all vegetative parts and even spikelets (Mew and Gonzales 2002). Use of brown spot resistant cultivars is the best way of economic and environment friendly management of the disease.

4.3.1 Isolation of the pathogen and inoculums preparation

Usually 10-12-day-old cultures can be used for the preparation of the inoculum. The cultures grown in Oatmeal agar medium can rubbed gently with an inoculating needle after adding a known volume of sterile distilled water to dislodge the spores. Flasks (250 ml) were shaken for 2-3 minutes. The suspension (spore and hyphal fragments) was strained through two layers of sterile muslin and washed thrice with sterile distilled water by centrifugation at 290g for 5 minutes. The desired concentration of the spore suspension was adjusted by adding an appropriate volume of sterile distilled water and the number of spores/ml were determined following haemocytometer counts.

4.3.2 Artificial inoculation

The standardized spore suspension of *H oryzae* with Tween 20 was sprayed on the clean and washed leaves of 40-42 days old plants with an atomizer sprayer. The inoculated plants were covered with moist polythene hags in order to maintain adequate humidity at the initial stage of infection and incubated as described earlier.

Percentage disease intensity was calculated using the following formula:

$$\text{Disease intensity } \% = \frac{\text{Sum of all numerical ratings}}{\text{No. of plants observed} \times \text{Maximum rating}} \text{ X } 100$$

Table 9. Scale for scoring of brown spot disease of rice (IRRI SES Scale, 2005)

Scale	**Disease severity**	**Host Response**
0	No disease observed	Immune
1	Less than 1%	Immune
2	1 – 3%	Highly Resistant (HR)
3	4 – 5 %	Resistant (R)
4	6 – 10%	Resistant (R)
5	11 – 15%	Moderately Resistant (MR)
6	16 – 25%	Moderately Resistant (MR)
7	26 – 50%	Susceptible (S)
8	51 – 75%	Susceptible (S)
9	76 – 100%	Highly Susceptible (HS)

4.4. Sheath rot (*Sarocladium oryzae, Fusarium* spp.)

The disease is caused by *Sarocladium oryzae* and *Fusarium* spp. and known by oblong to irregular brown or grey lesions on the leaf sheath that enclosed the panicle; emergence of panicle depends on the degree of the disease.

4.4.2 Preparation of inoculum and artificial inoculation

Conidia/mycelia from 10-12 day old slants were transferred separately for each isolate and mixed up with 10ml. of sterile distilled water. The solution (spore suspension) thus prepared was used for spraying in artificial inoculation wherever required. Conidia were scrapped from incubated plates/tubes into which 10-20ml of sterile distilled water was added. Spore suspension were filtered through nylon gauze mesh and spore concentration was adjusted to 5 x 104 conidia / mm The suspension had at least 10-12 spore / microscopic field under low power magnification. In few cases, the medium along with conidia also was used for artificial inoculation by filling with the help of cotton and string on the sheath of plant in cultivars.

4.4.3 Artificial inoculation

The inoculation was carried out in the evening hours when the temperature touched less than 26°C. The seedlings were spread uniformly with spore suspension through a mist sprayer, separate inoculation chamber was used for different isolates. in case of spore suspension spraying, the plants were kept cool place with running water through perforated plastic pipes and in other cases where the inoculum was paste and tied in the plant, the cotton was kept moistened during day time through pouring water on them.

4.4.4 Disease observation and scoring

Disease reaction was observed after 10-12 days of inoculation. The lesions on sheath were seen of different size and color. The infected samples were carefully examined and disease observations were recorded as per SES system of IRRI, Philippines and the percentages of infection /hill was recorded at reproductive stage.

$$\text{Disease incidence \%} = \frac{\text{Number of tillers infected}}{\text{Total number of tillers / hill}} \times 100$$

Table 10. Scale for scoring of rice sheath rot disease (IRRI SES Scale, 2005)

Scale	**Incidence: % diseased tillers**	**Host Response**
0	No Disease observed	Immune (I)
1	Less than 1%	Resistant (R)
3	1-5%	Moderately Resistant (R)
5	6-25%	Moderately susceptible (MS)
7	26-50%	Susceptible (S)
9	51-100%	Highly Susceptible (HS)

4.5 False smut (*Ustilaginoidea virens*)

Another important emerging diseases of rice incited by *Ustilaginoidea virens* (Teleomorph: *Villosiclava virens*).

4.5.2 Pathogen isolation and inoculum preparation

The pathogen is isolated from the false smut ball following the protocol described by Bag et al., (2021). Initially the smut balls were washed properly and unwanted dirt or soil particle are cleaned. Then the balls were sterilized for 3 min in 4% Sodium hypo chlorite (NaOCl) followed by 2-3 times washing with double distilled sterilized (dds) water. The balls are further sterilized for 1 min in 0.1% mercuric chloride and three times washing with dds water and dried with blotting paper. Later, balls are cut into pieces and placed on antibiotic (Ampicillin sodium salt @100µg/ml) mixed Potato Sucrose Agar (PSA) plate aseptically. The plates are allowed to incubate at 26 ± 1° C for 7 days (Bag et al., 2021). To get pure culture, 6-8 ml of dss water was poured on 25 days-old culture, and thoroughly shaking and 0.5 ml of the spore suspension was spread on water agar and are incubated at 26±1°C for 10-12 h. Petri plates are observed for single germinating spore. 5-6 single spores are picked and inoculated into PSA slants for incubation (Bag et al., 2021). The purified culture is used for mass multiplication in 100 ml potato sucrose broth (PSB) and incubated in an incubator shaker at 125 rpm at 25 ± 1°C for 12 - 14 days. The conidia (2×10^5 conidia/ ml) were harvested and suspended in sterile distilled water.

Artificial inoculation technique of FS culture: Culture of *U. virens* is transferred in PS broth and allowed it to grow for 25 days at 26 ± 1^0C with occasional shaking. Spore mass was dissolved in sterile distilled water, diluted and inoculated through injection of spore solution ($1x10^6$ spore /ml). 2 ml of spore solution is injected into rice plant at booting stage and kept the plant at 25 ± 1^0C for 2 days and >80% RH. After 2 days the plants are kept at 28 ± 1^0C. Again, spraying of spore solution was done at heading stage. FS ball is appeared 15-20 days after inoculation.

Scoring methodology to identify FS resistant donor: FS resistant donors are identified based on Comprehensive evaluation index score (**CEIS**) based on Zhang et.al. 2006. **CEIS** is calculated depending on the combine value of score of disease incidence and smut ball density score.

CEI= {(Score of disease incidence x 60) + (Score of smut ball density x 40)}/100

Disease Incidence % = (Total FS infected panicle/Total inoculated plant) x 100

Table 11. Scoring critical categorizing virulence level of FS pathogen (Zhang et al., 2006)

Disease incidence (%)	Score	Smut ball density (No. of FS ball/ panicle)
≤ 1	0	0
>1 but ≤ 5	1	1
>5 but ≤ 10	3	>1 but ≤ 5
>10 but ≤ 25	5	>5 but ≤ 10
>25 but ≤ 50	7	>11 but ≤ 15
>50	9	>50

Table 12. Scoring of CEI (CEIS) of reaction to rice entries of FS (Zhang et al., 2006)

Score	CEI	Resistant level
0	0	Highly Resistant (HR)
1	≤ 1	Resistant (R)
3	>1 but ≤ 3	Moderately Resistant (MR)
5	>3 but ≤ 5	Moderately Susceptible (MS)
7	>5 but ≤ 7	Susceptible (S)
9	>7	Highly Susceptible (HS)

4.6 Bakanae (*Fusarium moniliformae*)

Bakanae is also known as "elongation disease", "white stalk", and "man rice", etc. while in India it is commonly called as 'foolish seedling' or foot rot' disease. The disease causes severe yield losses. The typical symptom of this disease is pale yellowing and abnormal elongation of rice seedlings. The elongation is due to gibberellins (a plant growth hormone) and stunting for secretion of fusaric acid by the fungus.

4.6.2 Isolation of the pathogen and inoculums preparation

Fusarium fujikuroi isolates can be collected from infected plants. The PDA plates were inoculated with pure culture of the pathogen and incubated for 7-10 days at 25±1 °C for full growth. After 10 days, sterilized distilled water was poured on plates. The spore suspension was filtered through double layered sterile muslin cloth. The inoculum concentration is adjusted to $1x10^6$ conidia/mL. for pathogenicity tests and genotype screening.

4.6.3 Artificial inoculation

Healthy seeds of genotypes are surface sterilized for 2 min with 1% sodium hypochlorite followed by washings three times with dss water. For the next 24 hours, the seeds were soaked in distilled water. Seed were challenge inoculated with spore suspension ($1x10^6$conidia/mL) on the next day for 24 hr. seeds were dried under shade for 2 hr followed by sowing in portrays having sterilized soil and sand mixture at 3:1 ratio.

The disease incidence was recorded starting from 12 days after sowing when 100 % germination was observed in control treatments. The data on germination percentage, number of dead seedlings, elongation percentage and normal plants were taken. The disease incidence (including elongated and dead seedlings) was recorded and scored using 0-9 scale proposed by Fiyaz et al. (2014).

Table 13. Scale for scoring bakanae disease of rice

Sl No	Per cent disease incidence	Score	Disease Reaction
1	0-10	0	Highly resistant (HR)
2	11-20	1	Resistant (R)

3	21-40	3	Moderately resistant (MR)
4	41-60	5	Moderately susceptible (MS)
5	61-80	7	Susceptible (S)
6	80 and above	9	Highly susceptible (HS)

4.7 Bacterial leaf blight (*Xanthomonas oryzaepv. oryzae*)

Bacterial blight is one of the major disease of rice caused by bacteria *Xanthomonas oryzaepv. oryzae* (Xoo). The symptoms of the disease are known by water soaked lesions initially start at the tip of the leaves and later proceed downward along the both margin of the leaves. The lesions are light yellow to yellow or orangish yellow, later turning to grey (dead) depending on the virulence of the Xoo. In highly susceptible genotypes, lesions may extend to the entire leaf. Kresek or seedling blight causes wilting and death of the plants.

4.7.1 Pathogen isolation, Mass multiplication and artificial inoculation

Infected leaf samples should be collected and after surface steriliged using 0.1% sodium hypochlorite solution followed by 2-3 times washing and then chopped into small pieces (2-3 mm). and put in a vial having 2 ml sterile distilled water. After few minutes when the water in the vial became turbid, a loopful of water was streaked on a suitable medium like Nutrient agar or modified Wakimoto's Agar (MWA) or Peptone sucrose agar or Hayward's medium. After 2-3 days of incubation at 28 ± 1^{0}C, pinhead sized yellow colonies are picked up and further purified by culturing on the same medium. The pure cultures of *Xoo* isolates were maintained at 4^{o}C for short term storage and in 15% glycerol at – 80^{o}C for long term storage.

Confirm the pathogenicity of the pathogen by inoculating them on susceptible rice variety like Taichung Native 1 (TN-1). For this purpose, bacterial isolate grown on MWA plate for 3-4 days should be taken, after which the bacterial mass was scrapped and mixed with sterile distilled water to make an approximate concentration of 10^{8}-10^{9} cfu/ml. This bacterial suspension was then used for inoculating TN-1 plants at the maximum tillering stage following the leaf clipping method of Kauffman *et al.* (1973). The observations on bacterial reaction can be taken after 15 days of inoculation by measuring the lesion length or following the disease severity scale proposed by IRRI (IRRI SES Scale, 2005).

Scoring for disease resistance:

Disease scoring should be done preferably at 5-8 stage (bacterial leaf blight) for field test.

Table 14. Disease rating scale for field evaluation of germplasm

Scale	Disease severity: % leaf area diseased	Host Response
1	1-5%	Resistant (R)
3	6-12%	Moderately Resistant (R)

5	13-25%	Moderately susceptible (MS)
7	26-50%	Susceptible (S)
9	51-100%	Highly Susceptible (HS)

Lists of NRRI released varieties and land races of rice showing different reaction to diseases are given in Table 15.

Table 15. List of NRRI Released varieties and landraces resistant/susceptible to different rice diseases

Blast	
Resistant	Samalei,Savitri, Sarasa, Panidhan, Lunishree, Abhishek, Chandrama,Satya Krishna (CR Dhan 10), Chandan (CR Borodhan 2), Sahabhagidhan, Reeta (CR Dhan 401), Satayabhama (CR Dhan 100), Sumit (CR Dhan 404), Jalamani (CR Dhan 503), Jayanti Dhan (CR Dhan 502), CR Dhan 300, CR Dhan 202, CR Dhan 204, CR Dhan 205 (IET 22737).
Moderately Resistant	Kalinga-I, Shaktiman, Radhi, Hazaridhan, Geetanjali, Ketekijoha, Naveen, Rajalaxmi (Hybrid), Ajay (Hybrid), NuaKalajeera, NuaDhusara (CR Sugandh Dhan 3), Luna Suvarna (CR Dhan 403), Luna Sampad (CR Dhan 402), CR Dhan 701, CR Dhan 601, CR Dhan 500, Pyari (CR Dhan 200), Hue (CR Dhan 301), Improved Lalat, Luna Barial (CR Dhan 406), CR Dhan 305.
Susceptible	Ratna, Saket-4, Kalinga-II, Supriya, Indira, Sattari, Khitish, Utkalprabha, Udaya, Annada, CR 1014, Dharitri, Gayatri, Heera, Kalyani-II, Moti, Padmini, Sonamani, Tapaswini, Pooja, sarala, Durga, Anjali, Virender, Varshadhan, Hanseswari(CR Dhan 70), Swarna Sub 1, CR Dhan 40, Phalguni, NuaChinikamini, CR Dhan 501, Improved Tapaswini, Poorna Bhog (CR Basna Dhan 902), Luna Sankhi (CR Dhan 405), CR Sugandh Dhan 907, CR Dhan 303, CR Dhan 304, CR Dhan 201, CR Dhan 306 (IET 22084), CR Dhan 307 (Maudamani).
Sheath Blight	
Moderately Tolerant	Ramakrishna, Chandrama, Ketekijoha, Ajay (Hybrid), Varshadhan, Sumit (CR Dhan 404), CR Dhan 300, CR Dhan 306 (IET 22084), CR Dhan 408 (Chaka Akhi).
Moderately Resistant	CR 1014, Durga, Naveen, Rajalaxmi(Hybrid), Chandan (CR Boro Dhan 2), Hanseswari (CR Dhan 70), Sahabhagidhan, CR Dhan 601, Improved Lalat.
Suscepetible	Ratna, Saket-4, Kalinga-I, Kalinga-II, Indira, Khitish, Sarasa, Udaya, Annada, Dharitri, Gayatri, Heera, Padmini, Tara, Tulasi, Shaktiman, Sneha, DhalaHeera, Radhi, Pooja, Sarala, Virender, Satya Krishna (CR Dhan 10), Nuakalajeera, NuaDhusara (CR Sugandh Dhan 3), Luna Suvarna(CR Dhan 403), Luna Sampad (CR Dhan 402), NuaChinikamini, Satyabhama (CR Dhan100), Pyari (CR Dhan 200), Hue (CR Dhan 301),

	Jalamani (CR Dhan 503), Jayanti Dhan (CR Dhan 502), CR Sugandh Dhan 907, CR Dhan 303, CR Dhan 305, CR Dhan 201, CR Dhan 505, CR Dhan 203 (Sachala), CR Dhan 206 (Gopinath), CR Dhan 311 (Mukul).
Highly Susceptible	Supriya, Samalei, Sattari, Savitri, Utkalprabha, Neela, Khira, Moti, Panidhan, Vanaprabha, Lunishree, Sonamani, Tapaswini, Shatabdi, Hazaridhan, Sadabahar, Abhishek, Swarna Sub 1, CR Dhan 40, Phalguni, CR Dhan 501, CR Dhan 500, Improved Tapaswini, Poorna Bhog (CR Basna Dhan 902), Luna Barial (CR Dhan 406), Luna Sankhi (CR Dhan 405), CR Dhan 304, CR Dhan 202, CR Dhan 204, CR Dhan 205 (IET 22737), CR Dhan 101 (Ankit), CR Dhan 310 (IET 24780).
Seedling Blight	
Highly Resistant	Neela, Shatabdi, Swarna Sub 1, CR Dhan 203 (Sachala), CR Dhan 206 (Gopinath), CR Dhan 310 (IET 24780).
Resistant	Samalei, Savitri, Sarasa, Heera, Khira, Vanaprabha, Lunishree, Sneha, Vandana, DhalaHeera, Sadabahar, Naveen, Luna Suvarna (CR Dhan 403), Pyari (CR Dhan 200), CR Dhan 101 (Ankit), CR Dhan 408 (Chaka Akhi), CR Dhan 311 (Mukul).
Moderately Resistant	Kalyani-II, Tara, Tulasi, Pooja, NuaDhusara (CR Sugandh Dhan 3), NuaChinikamini, CR Dhan 701, Jayanti Dhan (CR Dhan 502), CR Dhan 305, CR Dhan 307 (Maudamani).
Susceptible	Ratna, Supriya, Indira, Sattari, Khitish, Kalinga-III, CR 1014, Sonamani, Sarala, Abhishek, Chandrama, Virender, Geetanjali, Ketekijoha, CR Dhan 40, Luna Sampad (CR Dhan 402), CR Dhan 501, Improved Lalat, Sumit (CR Dhan 404), Poorna Bhog (CR Basna Dhan 902), Luna Barial (CR Dhan 406), Luna Sankhi (CR Dhan 405), CR Dhan 300, CR Dhan 201, CR Dhan202, CR Dhan 505, CR Dhan 306 (IET 22084).
Highly Susceptible	Saket-4, Kalinga-I, Kalinga-II, Utkalprabha, Udaya, Annada, Dharitri, Gayatri, Moti, Padmini, Panidhan, Shaktiman, Radhi, Tapaswini, Durga, Anjali, Hazaridhan, Rajalaxmi (Hybrid), Ajay (Hybrid), Varshadhan, Satya Krishna (CR Dhan 10), Nuakalajeera, Chandan (CR Boro Dhan 2), Hanseswari (CR Dhan 70), Sahabhagidhan, Falguni, Reeta (CR Dhan 401), CR Dhan 601, CR Dhan 500, Satyabhama (CR Dhan 100), Hue (CR Dhan 301), Improved Tapaswini, Jalamani (CR Dhan 503), CR Sugandh Dhan 907, CR Dhan 303, CR Dhan 304, CR Dhan 204, CR Dhan 205(IET 22737).
Bacterial Blight	
Resistant	CR-1014, CR-2983-4, CR-Dhan 204, CR-Dhan 300, CR-Dhan 505, CR-Dhan 601, CR-Dhan 701, Gayatri, IR64-MAS, IR8, Jalamani, Jaya, Kalinga-III, Kalyani II, Khitish, Luna Barial, Moti, Naveen, Neela, NuaChinikamini, NuaDhusara, NuaKalajeera, Poorabhog, Pyari, Saket-4, Satyakrishna, Swarna -Sub1, Tapaswini-MAS, Varshadhan. **Landrace**: AC34960, Kasalath (ARC6000), ARC5791, ARC5774, Rudra Ahu (ARC5801), PaniKekoa (AC36308), Murgibadam (AC36386), Kalajeera.

Moderately Resistant	Annada, Bahadur, BPT-5204-Sub1, Chandrama, CR-Dhan 201, CR-Dhan 303, CR-Dhan 304, CR-Dhan 305, CR-Dhan 306, CR-Dhan 500, CR-Dhan 907, CR-Dhan-202, CR-Sugandh-Dhan 908, DhalaHeera, Durga, Heera, Indira, Kalinga-I, Ketekijoha, Luna Sampad, Luna Sanki, Luna Suvarna, Panidhan, Phalguni, Pooja, Reeta, Sahbhagidhan, Samalei, Sarala, Sarasa, Satabdi, Sattari, Satyabhama, Savitri, Sneha, Sonamani, Sumit, Supriya, Tapaswini, Tara, Udaya, Utkal Prava **Landrace**: Rogue (ARC5842), Nagra (AC36383), Kholi Hoi (AC36325), NalSathi (AC36294), Mugari Bao (AC36316), Bogi Bao (AC36322), ARC5686, Kakhuria (AC36435), Palasphula (AC35703), Badal Sali (ARC5846), ARC5772, KhasibaBedguti (ARC5912), BordubiSali (AC36277), Pakhi kala (AC36283), Dhio Bora (ARC5783), ARC5780, Badal Sali (ARC5769), ARC5799, Ryllo White (ARC5823), Laha Bora (ARC5972), Madhuri (ARC5971), Bahal Mathura (AC34976), Nepali Ahu (ARC5999), Mikir Ahu (ARC5993), ARC5792, TingiriSali (ARC5994), Balam (AC36256), PaniSali (AC36259), Kala mula (AC35700), Lal Dhepi (AC36764), Mayurkanthi (AC34985), Balum_II (ARC5976), Chinikamini, JangliJata, Badshabhog, Gobindabhog, Rangili Bao (AC36303), Dudheswar, Banskathi, Dudhasar (AC35025).
Susceptible	Abhisek, Anjali, Chandan, CR-Dhan 205, CR-Dhan 501, Dharitri, Geetanjali, Hanseswari, Hazaridhan, Hue, Jalamagna, Jayantidhan, Kalinga-II, Kamesh, Kshira, Padmini, Radhi, Ratna, Sadabahar, Shaktiman, TKM6, Tulasi, Vanaprava, Vandana. **Landrace**: Kajoli Bao, Kumoli Bao, Balami, Lakshman bhog, Ahu, Mnor, Kutia, Saket, Dhusuri, Balum, Weedy (ARC5833), Badal Bao, ARC5776, Nalibasumati, SialSali, Khandasagar, Jayaphul, ROGUE (ARC5778), Monail, Jete bora, Puak Dun, Manipur Lahi, Luchei, Nakoti, ARC5795, ARC5767, ARC5759, ARC5764, ARC5786, ARC5758, Kola joha, Tulsiphul, Dhusari, Bhundi, Mohongia, Maisa gapa, Nal bora, GodhiAkhi, Koimorali, Mohongia, Sarkarijoha, Kusuma, Maizo Tai, Kalamulia, Kasari Ahu, Kalajoha, Raspanjra, Sarobati, Prasad Bhog, Maizumgajaw, ARC5957, Sapurisaturi, Banspati, Jhili, Malta, GutiSali, Daria, Pokkali, Malbhog, Chadheinakhi, Laxman sal, Ranga Bao, Bhutia, Kabiraj Sal, Kalonunia, Balum, Kataribhog.
Brown Spot	
Moderatly Resistant	Khitish, Udaya, Annada, CR 1014, Dharitri, Sonamani, Sarala, Hazaridhan, Varshadhan, Satya Krishna (CR Dhan 10), Swarna sub 1, Reeta (CR Dhan 401), Luna Suvarna (CR Dhan 403), Pyari (CR Dhan 200), CR Dhan 304, CR Dhan 305, CR Dhan 202, Chandan, Kalinga-II, Ratna, Jalamani, CR-1014, Akul-Bal, BadshahaBhog. Basudha, Baudachampa, Bubaliachha, Budidhan, Gorumani, HaldiGundi, Jadumoni, Jalgudi, Kala Champa-R, Luna, Mohanbhog, Parbat Jeera, Parbat Jira, Ranisaheb, TulasiPhul, ARC-5786, ARC–5842, ARC–6039, ARC–6123, ARC–6130, ARC–6555, ARC–6556, ARC–7130, ARC–10171, ARC–10606, ARC–10656,

	ARC–10973, ARC–10983, AC-39742, ARC–11285, ARC–11551, ARC–11699, ARC–12004, ARC–7120, AC-261, AC-373, AC-431, AC-39760, AC-39833, AC-39839, AC-39845, AC-39879, AC-39910, AC-39915, AC-39916, AC-39966.
Moderately Suceptible	Ratna, Kalinga-I, Kalinga-II, Indira, Samalei, Savitri, Kalinga-III, Utkalprabha, Heera, Kalyani-II, Moti, Padmini, Panidhan, Tara, Tulasi, DhalaHeera, Radhi, Tapaswini, Durga, Shatabdi, Anjali, Sadabahar, Chandrama, Virendra, Geetanjali, Ketekijoha, Naveen, Rajalaxmi(Hybrid), NuaDhusara (Sugandh Dhan 3), Chandan, (CR Boro Dhan 2), Hanseswari(CR Dhan 70), CR Dhan 40, Sahbhagidhan, Phalguni,CR Dhan 701, CR Dhan 601, Improved Lalat, Improved Tapaswini, Poorna Bhog (CR Basna Dhan 902), Jalamani(CR Dhan 503), Jayanti Dhan (CR Dhan 502), CR Sugandh Dhan 907, CR Dhan 300, CR Dhan 303, CR Dhan 310(IET 24780), CR Dhan 409(Pradhan Dhan), CR Dhan 800, CR Sugandh Dhan 910, CR Dhan 311(Mukul)
High Susceptible	Saket- 4, Supriya, Sattari, Neela, Sarasa, Kalashree, Khira, Vanaprabha, Lunishree, Sneha, Vandana, Pooja, Abhishek, Ajay(Hybrid), NuaKalajeera, Luna Sampad(CR Dhan 402), NuaChinikamini, CR Dhan 501, CR Dhan 500, Satyabhama (CR Dhana 100), Hue (CR Dhan 301), Sumit (CR Dhan404), Luna Barial (CR Dhan 406), Luna Sankhi(CR Dhan 405), CR Dhan 201, CR Dhan 505, CR Dhan 204, CR Dhan 306 (IET 22084), CR Dhan 101(Ankit), CR Dhan 206 (Gopinath), CR Dhan 307(Maudamani), CR Dhan 408(Chaka Akhi), CR Dhan 507(Prasant), CR Dhan 506, CR Sugandh Dhan 908, CR Sugandh Dhan 909
False smut disease	
Highly Resistant	Ranjit, LunaSuvarna (CR Dhan 403)
Resistant	CR Dhan 907, Nuakalajira, NuaDhusara (CR Sugandh Dhan 3), Savitri, Annapurna, Heera, Sitabhog, Rangi, CSR 30, PR108, ADT 36
Moderatly Resistant	NuaChinikamini, Ketakijoha, Ajay, CR Dhan 303, Swarna, Govinda, Naveen, Pyari (CR Dhan 200), CR Dhan 409 (Pradhan Dhan), Sumit (CR Dhan 404),Shatabdi, Ambika, Gurjar, Bhaluki, Sugandha, Rajamani, Sudhir, IR20, IR36, Purnendu.
Moderateysuceptible	Utkalprabha, Swarna Sub1, Padmini, Ajaya, Gitanjali, Phalguni, KetakijohaReeta (CR Dhan 401), Gayatri, Padmini, Gitanjali, Phalguni, Lunishree, LunaSampad (CR Dhan 402), Improved Lalat, CR Dhan 501, Jalamani (CR Dhan 503), CR Dhan 310, Panidhan, Jagannath, Kalashree
Suceptible	Dharitri, Utkalprabha, CR 1014, CR 70,Hanshewsari), Sarala, CR 1018, Swarna Sub1, Samba Masuri Sub 1, Durga, N100, Rajalaxmi, Swarna, Sabita, Jalaprabha, Vasistha, Mahindra
Highly susceptible	Pooja, CR 500, Tapaswini, Varsha, Moudamani, Varshadhan, Tulasi, Moti, Mayurkantha, Moti, FR 13A
Bakanae Disease	
Highly Resistant	Sarasa, Khira, Sadabahar, Improved Tapaswini, Luna sankhi(CR Dhan 405), CR Dhan 311(Mukul)

Resistant	Neela, Kalashree, Nuakalajeera, Swarna Sub 1, Poorna Bhog(CR Basna Dhan 902)
Moderately Resistant	Saket-4, Kalinga-I, Kalinga-II, Khitish, Udaya, CR 1014, Kalyani-II, Tara, Lunishree, Shatabdi, Ketekijoha, Naveen, Varshadhan, Chandan (CR Boro Dhan 2), Phalguni, NuaChinikamini, CR Dhan 500, Pyari(CR Dhan 200), Improved Lalat, Sumit (CR Dhan 404), CR Dhan 305, CR Dhan 307 (Maudamani), CR Dhan 310(IET24780), CR Dhan 409(Pradhan dhan), CR Dhan 800
Suceptible	Supriya, Durga, Virendra, Hanseswari (CR Dhan 70), CR Dhan 601, Jayanti Dhan (CR Dhan 503), CR Dhan 303, CR Dhan 202, CR Dhan 505, CR Dhan 206 (Gopinath), CR Dhan 506
Moderateysuceptible	Ratna, Moti, Panidhan, Vanaprabha, Chandrama, NuaDhusara (CR Sugandh Dhan 3), Luna Suvarna(CR Dhan 403), Hue(CR Dhan 301), Jalamani(CR Dhan 503), CR Dhan 304
HighlySuceptible	Indira, Samalei, Sattari, Savitri, Kalinga-III, Utkalprabha, Annanda, Dharitri, Heera, Padmini, Tulsi, Sneha,Vandana, DhalaHeera, Radhi, Sonamani, Tapaswini, Pooja, Sarala, Anjali, Hazaridhan, Abhishek, Geetanjali, Rajalaxmi (Hybrid), Ajay (Hybrid), Satya Krishna(CR Dhan 10), Sahbhagidhan, Reeta(CR Dhan 401), Luna sampad(CR Dhan 402), CR dhan 501, CR Dhan 701, Satyabhama (CR Dhan 100), Luna Barial (CR Dhan 406), CR Sugandha Dhan 907, CR Dhan 300, CR Dhan 201, CR Dhan 2014, CR Dhan 306(IET 22084), CR Dhan 101(Ankit), CR Dhan 408 (chakaAkhi), CR Dhan 507(Prasant), CR Sugandh Dhan 910, CR Dhan 508, CR Sugandh Dhan 908, CR Sugandh Dhan 909

Source: Pathak et al., 2019; NRRI database https://icar-nrri.in/database-of-nrri/

Table 16. NRRI varieties resistant to multiple biotic stresses

Sl no	Varieties	Resistance for biotic stresses
1	Chandrama	Blast, Seedling blight
2	CR Dhan 311 (Mukul)	Seedling blight and Bakanae
3	Khira	Seedling blight and Bakanae
4	Lunishree	Blast, Seedling blight
5	Neela	False smut, Seedling blight, Bakanae
6	Sadabahar	Seedling blight and Bakanae
7	Samalei	Gall midge, Blast, Seedling blight
8	Sarasa	Blast, Seedling blight, Bakanae
9	Savitri	Blast, Seedling blight
10	Swarna Sub1	False smut, Bakanae, Seedling blight

Source: Pathak et al., 2019

5. Conclusion

Screening of genetic resources for evaluation of reaction to diseases and pests under artificial condition or natural field condition in endemic areas needs lot of efforts and resources. These activities also involve huge manpower and time. Moreover, in absence of standardized artificial testing protocol, natural screening is the only way to evaluate. Cataloguing of those genetic resources with their disease pest reation status will help many researchers working for developing resistant varieties. Efforts has been taken to catalogue NRRI released varieties and many rice landraces from various published articles as well as NRRI databases.

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Chapter 21

Integrated Approaches for Managing Stored Grain Insect Pests of Rice

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Abstract

Rice is India's most imperative food crop for more than sixty-five percent of the country's population. Every year, stored insect pest infestation causes about 3.51 percent loss of rice in India. A large number of insect pests (> 100 species) severely damage grains during storage and they also contaminate products with uric acid, scales and dead insects ultimately making stored products unfit for human consumption. Insect pests infest stored products in order to complete their life cycle inside them, meet food demand and to avail shelter resulting in qualitative and quantitative losses. Huge economic losses may result due to lack of proper knowledge about the life cycles, damaging stages of these stored pests as well as their storage techniques. Several synthetic insecticides have been used in the last few decades to reduce losses due to insect infestation and their repeated use has a negative impact on the environment, toxicity to non-targeted organisms and degrades grain quality, making it unfit for human utilization. So, in order to get rid of these synthetic pesticides, we employ integrated management of rice grain pests. It is a powerful and environmentally friendly method of controlling stored grain pests.

Keywords: Integrated pest management, Storage insect pests, Hermetic storage, Phosphine fumigation, Botanicals.

1. Introduction

Farming is the principal source of revenue for the majority of the world's population. The agricultural sector employs seventy percent of the Indian population. The population of developing countries like India is growing by the day. By 2050, the population is expected to reach 9.1 billion people, necessitating more than seventy percent of food production to feed the growing population (Godfray et al. 2010 ; Hodges et al. 2011). The use of land for non-food crops as a result of urbanization and climate change is a major impediment to meeting the food demand of a rapidly growing population. Food grain production in India has gradually increased over the last few decades as a result of the use of advanced agricultural activities and technological inputs. During the post-harvest period, each crop loses about ten percent of its grain. However, losses of grain in storage account for six percent of total losses due to the unavailability of proper storage facilities, insects, microorganisms and rodents (Prakash et al. 2016).

A large number of insect pests severely damage grains during storage and they also contaminate products with their excreta, which is unfit for human consumption. Pests infest storage grain in order to complete their life cycleinside them, meet food demand and provide shelter resulting in qualitative and quantitative losses. The tropical climate in India is ideal for the year-round occurrence of stored grain pests. The main reason for insect pestdamage to stored products is due to favourable environmental conditions for their growth and development. During various stages of grain processing such as harvesting, processing on the threshing floor, transportation of seeds or grains or storage, a large number of stored pests reach the grain. Some pests begin infesting seeds during the harvesting process and make their way to storage. Infestation is primarily caused by old bags and container, storage structures and cross-infestation (Pruthi and Singh, 1950).

2. Post harvest losses in rice due to storage pests

Various studies found that on a weight basis cereal crops, root vegetable crops and fruit & vegetable crops lost about 20 ,19 and %44 of their weight respectively, among different agricultural commodities but cereal crops lost the most (%55) on a calorific content basis (Gustavsson et al. 2011 ; Lipinski et al. 2013). Cereal grains which include rice, wheat and maize are the world's most popular food crops as well as the most widely accepted food crops in developing countries like India (IRRI, 2016). Maximum losses occurred during farm level operations (- % 85.28 87.77 % of total), with storage losses accounting for the majority (%40.99 - %33.92 of farm level losses). As post-harvest losses are a serious issue, we are not paying attention to them. Every year, stored pest infestation causes about 3.51 percent loss of rice in India (Bala et al. 2010). It is India's most important food crop, supplying sixty-five percent of the country's population (Anonymous, 2020). It contains a lot of vitamins, nutrients and minerals and it's also a good source of carbohydrates. It cannot be overstated how important it is in providing a direct or indirect source of income for billions of people. However, many stored grain pests infest rice grains, reducing grain weight and nutritional level while indirectly infecting mould, other contaminates, bad odour and heat damage problems, lowering the quality of rice grains and rendering them unfit for human consumption. Damaged grain prices will fall and consumers may offer lower prices for contaminated grains infested with storage insect pests (Sarwar et al. 2003).

3. Important stored grain insect pests of rice

Despite the fact that nearly 500 insect species have been linked to stored products, only about 100 of them cause economic losses to storage grains. Out of all storage pests, the majority of stored grain pests belong to the orders of coleopteran and Lepidoptera which primarily cause significant damage to rice products (Atwal and Dhaliwal, 2008). Between the two orders, coleopteran insects cause more damage than lepidopteran insects. In the case of coleopterans, both larva and adult cause grain damage, whereas in the case of lepidoptera, only larva destroy stored product. Apart from quantitative loss, they also deteriorate quality by contaminating the grains with their dead bodies, cast skins, excreta and with their webbings due to which the stored products get bad odour, colour and taste. Some of the storage insects are known to infest the grains in the field itself (rice weevil and Angoumois grain moth).A variety of major and minor insect pests infest stored rice, causing grain damage and deteriorating grain quality which can reduce profitability. They are classified as external or internal feeders based on their feeding habits (Table 1).

3.1 External feeders

These insects primarily feed on the grains outer surface, such as the outside parts of the germ and endosperm. These pests feed on intact grains or damage the germ portion of seeds. On the grains, various stages of insect pests are found.

3.2 Internal feeders

These pests are found inside the grain, as their name implies. This pest may lay eggs inside the grains and it will complete the entire larval and pupal period inside the grain before emerging as an adult. They have a direct impact on seed germination.

3.3 Secondary feeders

This group includes Insects and mites that develop after an initial infestation by primary feeders because they feed on cut already damaged grains, mould and detritus and dead insects and animal wastes.

Table 1: Categorization of important stored grain insect pests of rice.

A) Primary storage pests of rice: Pests that attack sound grains			
Common name	**Scientific name**	**Family**	**Order**
Internal feeders			
Rice weevil	*Sitophilus oryzae* L., *S. granarius* L.	Curculionidae	Coleoptera
Lesser grain borer	*Rhyzopertha dominica* (Fab.)	Bostrychidae	Coleoptera

Angoumois grain moth	*Sitotroga cerealella* (Olivier)	Gelechiidae	Lepidoptera
External feeders			
Red flour beetle	*Tribolium castaneum* (Herbst.) *T. confusum* (Jacquelin du Val)	Tenebrionidae	Coleoptera
Rice moth	*Corcyra cephalonica* Stainton	Galleridae	Lepidoptera
Indian meal moth	*Plodia interpunctella* (Hübner)	Phycitidae	Lepidoptera
Almond moth	*Ephestia* cautella (Walker)	Phycitidae	Lepidoptera
B) Secondary storage pests of rice: Pests that attack already damaged or broken grains			
Common name	**Scientific name**	**Family**	**Order**
Saw toothed grain beetle	*Oryzaephillius surinamensis* L.	Silvanidae	Coleoptera
Long headed flour beetle	*Latheticus oryzae* Waterhouse	Tenebrionidae	Coleoptera
Flat grain beetle	*Cryptolestus minutes* (Olivier)	Cucujidae	Coleoptera
Grain rice	*Liposcelis divinitorius* Mull.	Liposcelidae	Psocoptera
Grian mite	*Acarus siro* L.	Acaridae	Acarina

Economic losses may result from a lack of proper knowledge about the life cycles and damaging stages of these stored pests as well as their storage techniques. Several synthetic insecticides have been used in the last few decades to reduce losses due to insect infestation and their repeated use has a negative impact on the environment, toxicity to non-targeted organisms and degrades grain quality, making it unfit for human consumption. So, in order to get rid of these synthetic pesticides, we employ integrated pest management of rice grain pests. It is a powerful and environmentally friendly method of controlling stored grain pests (Kabir and Rainis, 2015). It consists of a combination of preventive measures such as traditional cleaning and sanitation, pest identification and monitoring, temperature and moisture maintenance inside and outside the storage structures, the release of predators and parasitoids and the use of botanicals and chemical pesticides. As a result, the integrated management of stored grain pests approaches must be implemented at all times to manage them effectively.

4. Integrated management of stored grain insect pests of rice

Integrated pest management, as the name implies there's integration of different tactics used to minimize the activities of stored grain insect pests which includes physical, cultural, biological, mechanical and chemical methods. It is an approach for controlling pests that takes advantage of the broad variety of management practices that are available to farmers. However, if the desired results are not obtained within the specified time limit, we must resort to the use of chemicals to manage stored pests in storage structures or godowns (Patil et al., 2019). It is important to remember that the combination of these measures for pest management should be economically feasible and environmentally acceptable, with no risk to humans, non-targeted organisms or the environment also.

4.1 Precautionary measures/ Cultural methods

Prevention is better than cure which requires good hygiene and sanitation. The precautionary measures for managing the stored grain insect pests include the following

a) Drying: The grains should be cleaned and dried well in the sun so as to have moisture content of 13 per cent (for milled rice) and 15 per cent (for paddy). If neglected, excess moisture in the grain causes heating and development of insect pests and mould which leads to disagreeable odour, deceleration and even caking.

b) Cleaning: Threshing yard and post harvest machineries (combine harvesters, threshers and dryers) should be cleaned properly to avoid cross infestation and spread of stored grain pests.

c) Storage structure should be well ventilated, hygienic, rodent proof, bird proof and damp proof to avoid pest infestation.

d) Cracks, holes and crevices in the walls, floors and ceilings of the store house should be sealed properly to prevent the cross infestation.

e) Before stacking the grains, godowns, store rooms and receptacles should be cleaned and made free from insects through disinfestations by dusting malathion 5% or treating the godown floor and walls with DDVP at 1:150 dilution in water to avoid cross infestation of new stock.

f) The bags or bins can be made damp proof by providing dunnage of bamboo/ wooden stand/ crates of bamboo poles or wooden crates.

g) The bags should be stacked in such way as to allow proper ventilation and sufficient space for periodical inspection.

h) Dusting of malathion 5% dust on the top of the bags as a thin film.

i) To prevent the cross infestation in the godown the new arrivals of stocks should not be stored along with old or infested stocks.

j) Regular inspections of stock allow early detection of problems and enable corrective action to be taken before damage becomes severe.

4.2 Mechanical methods

This is the most important method for reducing the infestation of stored pests after grain harvesting. Sanitation, drying of stored products, cleaning and sieving/ winnowing are all partof this method. In general, good sanitation measures are a good starting point when it comes to making integrated management programmes a success. (Morrison et al. 2019) evaluated that poor sanitation can reduce the efficacy of other integrated management methods such as biological, chemical and modified atmosphere methods resulting in a 1.3 to 17 fold decrease in efficacy in poor sanitation compared to good sanitation.

4.2.1 Drying

Before storing rice in godowns or any storage units, the most commonly used practice is drying. It can be done either manually or mechanically (Sun or shade drying). Natural drying, also known as sun drying, is a traditional drying method that is popular in developing countries. As we all know, grains are harvested at a high moisture content to reduce the shattering losses in the field during cutting of paddy using tools such as sickle, knife, scythe, cutters etc.To reduce pest infestation rice grain should be sun dried and the moisture content should be reduced to thirteen percent before storing (Baloch, 2010). If it is not properly dried, it allows mould growth and damage, discolouration and respiration and high losses during commodity storage, milling and marketing. As a result, drying is the very important step after harvesting to maintain grain quality, minimize losses due to pest infestation and reduce transportation costs. Hence the grains should be cleaned and dried well in the sun so as to have moisture content of 13% (for milled rice) and 15% (for paddy). If neglected, excess moisture in the grain causes heating and development of insect pests and mould which leads to disagreeable odour, deceleration and even caking.

4.2.2 Sieving

In developing countries such as India, this practice is commonly used to clean grain products after drying them for storage in godowns or bins. To eliminate the conditions that favour storage pests, this process sieves and separates all broken grains or infested grains from sound grains and other foreign materials such as straw, small stones, chaffy grains and weed seeds. If grains are not properly cleaned before storing, it creates an environment conducive to insect infestation, mould growth, grain colour changes and also damage to post harvest processing equipments. As a result of this operation, a significant amount of grain may be lost, accounting for upto 4 % of total production (Sarkar et al. 2013).Threshing yard and post harvest machineries (combine harvesters, threshers and dryers) should be cleaned properly after sieving to avoid cross infestation and spread of stored grain pest.

4.3 Physical methods

Stored insect pests will be controlled by manipulating the physical environment or applying any physical treatment to both grains and insect pests. The temperature and moisture content of grains are two variables that fall under the category of physical environment. Irradiation, Acoustic/Soundand Hermetic storage are among the physical treatments.

4.3.1 Heating

This method is very effective and widely acceptable at market because of being free of residue. There are different suitable methods are used forheating grains like hot-air convection, infrared and microwave radiation but most heated air grain drier cannot grain heat uniformly and efficiently to desired temperatures. The simple and cost effective method of heating mostly used by all farmersis hot air/hot water alone or combination with controlled atmosphere (Beckett et al. 2006). The hot air is used increase the temperature of grain which lies above the thermal limit of survival of stored pests. Heat disinfestation treatment is easy to use and leave no chemical residue so that it affects mortality of insect pests when exposed to hot air such as duration of exposure, temperature, type of pests and stages of that pest. When grain temperature is between 60-65^{0}C for few seconds or few minutes will necessarily kill all the storage pests of rice. The same minimal temperature be very effective in killing the stored pests whichever method is used for heating of grain. If heating is introduced too quickly the grain become crack, harden, brittle and seed will not germinate as embryo is damaged (Shadia, 2011).

4.3.2 Cooling

It is an ancient control method used to prevent spoilage by stored insects in godowns for storing commodities (Banks and Fields, 1995). Temperatures between 25 and 33^{0}C are ideal for growth and development of stored product pests (Table 2). The lower temperatures between 13 and 25^{0}C slows the developmental rates, feeding, fecundity and survival of pest insects but extends the developmental period before their population grows to the point where they cause significant damage to grains (Logstaff and Evans, 1983). When insect pests are stored in cool temperatures (10-20^{0}C), they become acclimatized and their cold hardiness increases by 2-10times. Mites and insects cannot develop at 2^{0}C in moist grains, but they can survive for a longer period of time and cause infestations when the temperature rises or the environmental conditions are favourable. Burrell (1967) showed that cooling stops the development of insects in storage houses, thereby preventing grain infestations, but the insects are not killed. As a result, this method of control is preventive rather than curative. According to Burks et al. (1999) low temperatures check the emergence of unparasitized larvae of the rice weevil, *Sitophilus oryzae* (L.) while having no effect on the emergence of the parasitoid, *Anisopteromalus calandrae*.

Table 2: Response of stored product insects to temperature

Zone	Temperature (^{0}C)	Effects
Lethal	>62	Death in less than 1 min
	50 to 62	Death in less than 1hr
	45 to 50	Death in less than 1hr
	35 to 42	Populations die out

Sub-optimum	35	Developmental stops
	33 to 35	Slow development
Optimum	25 to 33	Maximum rate of development
Sub-optimum	20 to 25	Slow development
	13 to 20	Development slow or stops
Lethal	3 to 13	Death in days and movement stops
	-10 to -5	Death in weeks to months if acclimatized
	-25 to -15	Death in minutes, insect freeze

Source: Banks and Fields (1995), Fields and Muir (1996)

4.3.3 Irradiation

Because an electron beam can be turned on and off, it is usually safer and easier to work with than an isotope, which is always radiating and must be shielded from humans (Fields and Muir, 1996). Lower doses of radiation will completely kill or sterilize store grain pests as well as any eggs that are present inside the grains. Radiation treatments, such as microwaves and X-rays, are applied to grains in a variety of ways prior to storage to prevent insect pest infestations. The exposure of gamma rays irradiation with at 0.5 kGy will result in complete mortality in 14 days for rusty grain beetles, 70 days for saw-toothed grain beetles, 200 days for grain mites and 28 days for red flour beetles and for the management of *Oryzaephilussurinamensis*, a synergistic interaction of microwaves radiation can be used with cold storage. In an integrated management programmes, this technique would offer useful and environmentally friendly action (Valizadegan et al. 2009).

4.3.4 Hermetic storage

Hermetic Storage means airtight storage which is an age old traditional technique used from our forefathers, ancestors for storing the agricultural commodities. The wax seals found on ancient Greek and Roman jars known as “amphoras” tell us that hermetic storage has been used to preserve grains for more than 2,500 years ago. In hermetic storage creates an airtight barrier between the commodities stored in them and the outside atmosphere i.e. No exchange of air, which kills the insects by asphyxiation (lack of oxygen). Continuous respiration by the commodity as well as insects inside the hermetic storage products increases the level of CO_2 and depletes the level of oxygen in the hermetically stored products. This method also creates moisture barrier between the commodity stored and the outside atmosphere; due to this there is nosignificant variation in the moisture content, as the hermetic storage is sealed i.e. No exchange of moisture.

The hermetic storage technique is regarded as a superior alternative to fumigation at storage structures in tropical climates. In Sri Lanka Donahaye et al. (2001) pioneered the use of hermitically sealed plastic liners to store paddy/rice in tropical environments. Here the atmosphere has been modified by hermetically sealing the container, resulting in a low concentration of O_2 and a higher concentration of CO_2 after a few weeks of storage (Busta et al. 1980). As a result of the high concentration of CO_2 and low concentration of O_2 developed in the hermetic storage system, insects present inside the grain will die and the growth of fungi is hampered which may produce aflatoxin (Emekel et al. 2001). Similarly, Hocking (1990) reported maintaining the atmospheric concentration of oxygen (1-2%) and carbon dioxide (9-9.5%) at a common room temperature for 1-4 days, are detrimental to all stored grain pests for their survival.

The commonly available hermetic storage products are mentioned below

a) **Super bags:** It is smaller version of hermetic storage products and made up of food grade polyethylene with 60-78 micron thickness having gas barrier coating. It can be used as individual bag or as liners in jute or paper bags. They are used for storing of all types of grains, pulses, cocoa, coffee beans, seeds, spices or any other dry agriculture products in small quantity. Commodities can also be stored in super bags during transit in trucks or in container as well as during storage in warehouses or domestic storage purpose for longer period. Bags can be sealed by either dual groove zip lock system or simple cable ties.

b) **Hermetic cocoon/ Mega cocoon:** These are used for storing and organic fumigation of any grains, seeds, pulses, cocoa, coffee beans, barley, spices and any other dry agriculture products in bagged condition. It is made up of light weight UV resistant PVC (polyvinyl chloride) plastic of 0.83 mm thickness. The simple two-piece cocoon consists of a top cover and bottom floor piece joined together with a PVC tongue and groove zipper. It comes as folded & packed in carry bag for easy transportation and can be used in indoor as well as outdoor. It is near complete air tight and moisture tight, which doesn't require separate infrastructure and can be set up in open filed. It has rodent resistant design i.e. when properly installed it becomes so stretched and slippery that the rodents incisors can't able to catch hold of it. It is extremely cost effective and designed for storage of any dry agricultural products. Artificial infusion of CO_2 gas is possible from external sources like CO_2 cylinders for hastening the process of O_2 depletion leading to faster insect kill. It is available in different capacities ranging from 1 to 1050 tonnes (for 1 tonne is called as GrainSafe and 1050 tonne is MegaCocoon). The other variants available are 5, 10, 20, 50, 100, 150, 300, 525, 640 tonnes.

c) **Transafe liner:** It is a gas& water tight liner used during transport of commodities in shipping containers during transit causing natural fumigation by hermetic principle. A multilayer bag to be inserted in containers (20'and 40') enabling development of hermetic atmosphere in the container. During transit time the container will be "self-fumigated" due to depletion of O_2% and increase in CO_2% inside the container ensuring arrival of the insect free stocks. Due to impermeability to moisture and water vapour it prevents condensation and commodity damage due to temperature fluctuation during transit in voyage.

4.3.5 Controlled or modifiedatmospheric storage

Technically controlled atmosphere storage is subjecting the harvested produce or stockto controlled condition of gases, temperature and pressure. Application of controlled atmosphere for storage of grain involves the use of higher concentration of CO_2 (9.0– 9.5%) and low concentration of O_2 (2–4%). This situation is very lethal to all insects and even microbes. Due to lack of oxygen, the aerobic microbes and living insects cannot survive. This technology is obviously very expensive as compared to the former points discussed; hence it is mainly used for high value crops only.

The effectiveness of modified atmosphere in controlling insect pests is dependent on various abiotic (gas composition, gas pressure, RH, temperature and exposure period) and biotic (species of insect, damaging stage, size and distribution of infestation) factors. The moisture content, gas concentration gradients within a grain bulk, efficiency of the gas generating unit, the problems related to the sorption of CO_2 on the grain and leakage rate of storage structure are other aspects that must be taken into account for modified atmosphere storage. Different insect species require different atmospheres for their control. Even within the insect species, different strains or populations require different atmospheres for their control depending on their physiology, environmental conditions, temperature and relative humidity. Hence it is not possible to generalize the results obtained from controlled atmosphere studies of one species to another.

4.3.6 Acoustic/Sound

This method is used to provide information about the status of pest infestation within grain commodities for continuous monitoring and rising pest infestation levels before they cause economic damage. This device improves the checking for pest infestation of many stored products by providing a measure of transparency, but it is not easy to monitor without destroying samples. Such advancements benefit pest managers, regulators and researchers. There are now numerous acoustic devices available that improve the effectiveness and reliability of stored pest identification (Mankin et al. 2011). *Sitophilus oryzae* inside grain can be guessed from small distances of upto 10-15cm by hearing the sound (Vick et al. 1988). Adult *Tribolium castaneum* is found at upto 18.5cm due to the use of these devices (Hagstrum et al. 1991). After 5 minutes of exposure to 1MHz sound @ 14.5W cm^{-2} at 26^0C, all life stages of *Sitophilus granarius* will be killed in cereal grains,but their commercial use is not possible (Banks and Fields, 1995).

4.4 Biological control

Biological control is not that effective in stored pest management, but it has become an important part of integrated management strategies. In this control method, the use of predators, parasitoids or microorganisms is followed to control stored grain pests. Both predators and parasitoids are host specific, but insect pathogens have a broad spectrum of hosts (Kavallierators et al. 2014). Among the biological agents, parasitoids belonging to the hymenopterousgroup play a major role in controlling stored grain pests like rice weevil, lesser grain borer;angoumios grain moth, saw-toothed grain beetle and rice moth (Table 3). Although parasitoidskill many stored grain pests, this does not provide complete protection because the grain was previously infested with stored pests. *Theocolaxelegans,* a parasitoid wasp attackspests whose immature stages have completed their time periods inside the grains, such as rice weevil, lesser grain borer and angoumois grain moth (Flinn et al. 2006). The suitable microbial control strategies includeentomopathogenicfungi (EF), which create disease symptoms and affect the growth and development of insect pests (Batta, 2016). For control of stored pests infestations,the most widely used fungal species are *Beauveriabassiana* and *Metarhiziumanisopliae.* But the limitation of this method is that it is very expensive, time consuming and the rearing of these bioagents is very difficult.

Table 3: Predators and parasitoids used to manage stored grain pests of rice

Name of Bioagents	**Family**	**Order**	**Used against stored pests**
Braconhebetor Say	Braconidae	Hymenoptera	*Oryzaephilus surinamensis*
Venturiacanescens (Gravenhorst)	Ichneumonidae	Hymenoptera	*Oryzaephilus surinamensis*
Lariophagusdistinguendus Forster	Ptermalidae	Hymenoptera	*Sitophilus granarius*
Venturiacanescens	Pyralidae	Lepidoptera	*Plodia interpunctella*
Anisopteromaluscalendrae (Howard)	Pteromalidae	Hymenoptera	*Oryzaephilus surinamensis*
Anisopteromaluscalandrae (Howard)	Pteromalidae	Hymenoptera	*Cephalonomi awaterstoni*
Peregrinator biannulipes (Montrouizer)	Reduviidae	Hemiptera	*Sitophilus granarius*
Xylocoris flavipes (Reuter)	Anthocoridae	Hemiptera	*Plodia interpunctella*
Lyctocoris spp	Anthocoridae	Hemiptera	*Sitophilus oryzae*
Amphibolus wenator(Klug)	Reduvidae	Hemiptera	*Sitophilus oryzae*
Scenopinus fenetralis (L)	Scenopinidae	Diptera	*Cephalonomia waterstoni*
Ventura canescens	Ichneumonidae	Hymenoptera	*Sitophilus oryzae*
Braconhebetor Say	Braconidae	Hymenoptera	*Sitophilus oryzae*
Antrocephalus spp	Chalcididae	Hymenoptera	*Sitophilus oryzae*

4.5 Botanicals

Botanical pesticides are very effective control methods used in integrated management of stored grain pests because they are biodegradable, eco-friendly, do not cause any harmful effects on beneficial insects and do not degrade the quality of stored products. The plant-derived chemicals will have produced repelling activity, deterring and ovipositional activity on plants or playing havoc with behaviour and physiology in various ways. Various plant products have been tried with a good degree of defensiveness against stored grain pests (Srinivasan, 2008). When plant parts like leaf, seed powder, kernel extract, bark and root are mixed with grains, it prevents pest infestation of stored grains by reducing egg laying; if they lay eggs, adult will not emerge, reducing seed damage.Plant-based essential oils haveantiparasitic, bactericidal, fungicidal, antiviral and insecticidal agents against stored grain pests (Table 4). The control of all coleopteran pestinfestations ofstored grainsis very effective due to the activity of essential oils. The infestation of rice weevil (*Sitophilus oryzae*) is reduced when turmeric powder is treated with rice grain 3.25% (w/w) (Perez et al. 2010). Secondary metabolites of plants like terpenoids, alkaloids and phenols act as attractants or repellents against stored pests, which affect the growth and development of insect pests, moulting, oviposition, fecundity and adult emergence, which act as good protection measures (Bennett and Wallsgrove, 1994). So the use of botanical pesticides for use against pest infestation is widely accepted in developing countries like India (Rajashekar et al. 2010). Phytochemicals have also been used in the form of aqueous or solvent extracts, powders, slurries, volatiles, oils or shredded segments against stored pests. Hence, botanicals play a major role in the substitution of synthetic pesticides against all the stored grain pests that damages stored commodities due to their easy availability, least mammalian toxicity and faster degradation process leaving no residues.

Table 4: Plant volatile organic compounds used against stored grain pests of rice

Plant species	**Family**	**Active ingradient**	**Target pest**
Carum carvi	Apiaceae	Carvone, Limonene, (E)- Anethole	*Rhizopertha dominica* *Sitophilus oryzae*
Chamaecyparisobtusa	Cupressaceae	Bornyl acetate	*Sitophilus oryzae*
Aloysiacitriodora	Verbenaceae	Citronella and sabinene	*Tribolium castaneum* *Tribolium confusum*
Aloysiapolystachya	Verbenaceae	Carvone and limonene	*Tribolium castaneum* *Tribolium confusum*
Artemisia annua	Asteraceae	1,8-cineole	*Tribolium castaneum*
Citrus spp.	Rutaceae	Limonene, Eugenol	*Sitophilus oryzae* *Tribolium castaneum*
Colocasia esculenta	Araceae	2,3-Dimethyl-maleic anhydride	*Sitophilus oryzae* *Tribolium castaneum*

Convolvulus arvensis	Convolvulaceae	Hexadecanioc acid	*Rhizopertha dominica* *Sitophilus oryzae*
Conyzadioscordis	Asteraceae	Dicotlyhe-xanedioate	*Sitophilus granarius* *Tribolium castaneum*
Coriander sativum	Apiaceae	Linalool	*Rhizopertha dominica* *Sitophilus oryzae*
Cupressuslusitanica	Cupressusaceae	Umbellulone and α-pinene	*Tribolium castaneum* *Sitotroga cerealella*
Eucalyptus spp.	Myrtaceae	α-Terpinene; 1,8-cineole; α-pinene	*Sitophilus oryzae*
Eucalyptus saligna	Myrtaceae	p-Cymene	*Sitophilus oryzae* *Tribolium castaneum*
Feoniculumvulgare	Apiaceae	Phenylpropenes, Estragole (E)-anethole, (p)-fenchole	*Sitophilus oryzae*
Juniperusfoestidissina	Cupressaceae	Citronellol	*Trogoderma granarium*
Lantana camara	Verbanaceae	Coumaran	*Sitophilus oryzae* *Tribolium castaneum* *Rhyzopertha dominica*
Malaleucacajuputi	Myrtaceae	Terpine-4-ol, y-Terpinene Terpininolene	*Sitophilus oryzae* *Tribolium castaneum* *Rhyzopertha dominica* *Ephestia kuehniella*
Nardostachysjatamansi	Caprifoliaceae	Aristolone	*Sitophilus oryzae* *Tribolium castaneum*
Ocimumcanum	Lamiaceae	Linalool	*Sitophilus granarius* *Tribolium castaneum*
Ocimumkilimandscharium	Lamiaceae	camphor	*Sitophilus oryzae*
Rosmarinus officinalis	Lamiaceae	camphor	*Sitophilus oryzae*

Source: Talukder F. A. (2006) ; Rajendran, S. and V. Sriranjini (2008)

4.6 Chemical control

There are two methods of chemical control used to manage stored grain pests in rice.

1. Prophylactic treatment
2. Curative treatment (Fumigation)

4.6.1 Prophylactic treatment with chemical

It is undertaken when few insects are found crawling on stored rice bags. It is usually done to prevent cross infestation.These protectant chemicals are specifically used against cereal grains and are sprayed on grains to protect them from insect infestation for 6-9 months in storage structures or godowns.Before stacking the bags containing grains, the receptacles, godownsand store rooms should be cleaned and made free from insects through disinfestations by dusting malathion 5% or treating the godown floor and walls with DDVP at 1:150 dilution in water to avoid cross infestation of new stock.Grain protectant chemicals are widely used because buyers prefer grains that have only been treated with grain protectants because they have no chemical residue and can be consumed. Because it leaves no residue on grain, the insecticide carbaryl is used as a chemical control against pest infestation on feed grain. If a protectant is added to infested grain before it is treated with phosphine or dichlorvos, the pest infestation is completely controlled. The chemical treatment method is less effective than fumigation;the commonly used grain protectant chemicals for managing the stored grain insect pests include the following

a) **Malathion 50% EC** diluted with water @ 1:100 and requires about 3 litres of aqueous solution to treat 100m^2 area for surface treatment on bags containing stock, walls and alleyways. It will be effective for 15-20 days.

b) **Deltamethrin 2.5% WP:** Dissolve 40 g in 1 litre of water and require about 3 litres of aqueous solution to treat 100m^2 area for surface treatment on bags containing stock, walls and alleyways. It is effective for 90 days.

c) **DDVP 100 EC:** Used for air-charging in empty spaces, floor and walls of godown. It is diluted with water @ 1:150 require 3 litres of aqueous solution to treat 100 m^2 area.

4.6.2 Curative treatment with chemical (Fumigation)

For controlling insect pest infestations on grain, we use different types of control methods, but fumigation is one of the most effective, in which a poisonous gas is released into a closed environment containing pests and grain by using it as a grain fumigant. It is used to control stored pests in buildings, warehouses, stored products, godowns, bags and bins. When aluminium phosphide tablet comes into contact with water, phosphine gases are released and they enter the bodies of insects through the spiracles, spread to the trachea and tracheoles and finally reach the haemolymph content, where they stop the activity of respiratory system, eventually stored insect pests will die (Brattsten et al. 1986). For the control of stored grain pests, the most commonly used fumigant is phosphine (Rajendran and Sriranjini, 2008). Carbon disulphide, carbon tetrachloride, chlorpicrin, ethylene oxide, sulphuryl fluoride, ethylene dichloride, sulphur dioxide, ethyl formate, carbon sulphite and ethylene dinitrile are also used as fumigants. Phosphine gas interferes with the hatching of coleopteran insect pests such as *S.oryzae*, *R.dominica*, *T.castaneum* and *O.surinamensis* (Rajendran et al. 2004). Fumigation is ineffective unless the stored structures are completely sealed and the grain temperature is kept above 50°C. To control stored grain pests, contact insecticides such as hydroprene and cyfluthrin are used. Cyfluthrin insecticidesare more potent than hydroprene (Banks and Field, 1995). Although this method is very effective in controlling stored insect pests, it is not environmentally friendly and fumigated grainis not suitable for human consumption for 10-15 days after fumigation. They need to be aerated to remove the residue of fumigants.

4.6.2.1 Phosphine fumigation

Fumigation is a process of exposing the grain infested with insects to the fumes of a chemical in an enclosed space at a lethal dose. This is a curative method to control infestation in grain and is resorted as soon as the infestation of pest is noticed. It is undertaken under heavy infestation of stored grain pests by using Aluminium phosphide tablets. Presently Aluminium Phosphide 56% (F) available in the form of tablets is used as fumigant. Each tablet weight is about 3 grams and emanating 1 gram of phosphine during its disintegration. This disintegration into Phosphine, carbon dioxide and ammonia takes place when the tablet comes in contact with atmospheric moisture. Phosphine generated is a potent toxic gas and act as respiratory poison for stored grain pests since it can penetrate 10 meters towards all directions. Phosphine gas is six times heavier than air, it tends to move downwards.Pre-monsoon fumigation: One round of pre-monsoon fumigation of all the available stocks in covered stores is to be ensured for better maintenance of the stock in insect free condition.Dosage for stack fumigation under airtight cover is 3 tablets weighing 3g each per ton of grain and for shed fumigation 21 tablets of 3 g each for 28 cubic meters.The tablets should be wrapped in cotton pouches before placing them in the stacks, which helps to discard the remnants after completing the fumigation.

Precautions to be taken during phosphine fumigation

a) The Phosphine gas which is released in the process of fumigation is highly poisonous hence; all precautions should be taken by personnel involved.

b) The fumigation should be carried out by following standard procedures under the supervision of trained personnel in appropriately prepared fumigation enclosures.

c) The stock should not be fumigated in rainy days as phosphine is highly inflammable.

d) Entire stack should be covered with Multi-layer cross laminated (MLCL) fumigation covers (200 GSM) and pinholes should be closed properly for successful fumigation.

e) All the corners of plastic cover should be plastered with 6 inch thick layer of mud/ sand snake/ adhesive tapes to prevent leakage of Phosphinegas.

5. Conclusion

As we know, 70-75 percent of total stored grain is stored for consumption as food, feed and seedpurposes after post-harvesting operations. The best and most effective method for minimizing losses due to stored pests and mites of stored grains at storage units and structures is integrated pest management of stored grain pests. Integrated management is now the best and safe method that will ensure food security in India by preserving the quality and quantity of food grains while increasing their economic value and providing nutritive food to malnourished and poor people.

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Chapter 22

Socioeconomic implications of climate change on rice farming

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Abstract

Rice (*Oryza sativa* L.) grain is of paramount importance when it comes to ensuring food security worldwide. However, the performance of agriculture depends on the climate, so is the rice crop too. Globally, studies have simulated different climate change scenarios and predicted rice yields under different scenarios and the results projected both optimistic as well as pessimistic views. But, pessimism overweighs optimism when it comes to impacts. In this chapter, we have summarised the possible impacts of climate change concerning rice farming and discussed their socioeconomic implications, which includes a surge in farm-level abatement cost, decline in marketable surplus, supply shocks, crop diversification etc. The social implications of climate change on rice holds much significance for the food policy of India and provide the directions for future food policy actions.

Keywords: Climate change, Rice farming, Socioeconomic impacts, Marketable surplus

1. Introduction

Environmental risks are the most perceived risk worldwide, as reported by the World Economic Forum Global Risk Perception Survey 2021-2022 (WEF, 2022). Among these environmental risks, one or another hovers around climate change. Despite being a perpetual phenomenon, climate change gained real traction in the mid 20th and early 21st century, when it became a buzzword. As per the Intergovernmental Panel on Climate Change (IPCC) synthesis report, by 2100, the mean surface temperature of the planet is likely to increase by 1.4 to 5.8°C (IPCC 2007), while the extreme events like flood, drought, cyclone, land degradation, water scarcity, expansion of deserts, loss of biodiversity, increased sea level etc. are likely to become more frequent (IPCC 2007; Srinivasa Rao et al. 2019). It is also reported that climate change would place higher penalties on the tropics (Antle 2008) and developing countries (Rosenzweig and Parry 1994) due to rising sea level and their heavy dependence on rainfed agriculture. Further, Ravindranath (2007) reported that south Asia may get warmer by 2-6°C during the 21st century while Lonergam (1998) has predicted that the temperature in India to change between 2.3 to 4.8°C following doubling ambient CO_2 concentration from the pre-industrial level. In India, arid and semi-arid zones would experience changes in precipitation rates, while the west and semi-arid zones will receive higher rainfall than the normal and the central parts will experience 10-20 per cent rainfall reduction during winter by 2050 (Srinivasa Rao et al. 2019). It is worth mentioning that climate change presents the single biggest threat to sustainable development everywhere (UN), hence the favour of climatic variables is crucial to attaining sustainable development goals (SDGs). Moreover, agriculture is essential to achieve SDGs such as zero hunger, no poverty, and responsible consumption, understanding the effects of climate change on agriculture is critical to influencing future course of action and minimizing the causes of climate change.

India supports 17.7 and 10.7 per cent of the human and livestock population, respectively from meagre 2.4 per cent of global land resources, 8 per cent of water resources and 3.28 per cent of global GDP. For India, it would be preposterous to the thought of food security of its burgeoning human population without the rice and wheat grains, which make a major share in the pie of the national food security mission (NFSM) and public distribution system (PDS). Rice (*Oryza sativa* L.) is a staple source of dietary energy in India. Apart from being an important dietary energy source, it is the source of livelihood to 40 per cent of rural poor and cultivated by 67 per cent of farm families (Pathak et al. 2020). In India, rice is cultivated in *Kharif* as well as in summer seasons in almost all the states; under rainfed and irrigated land; below sea level at Kuttanad (in Kerala) to the mountainous region of Jammu and Kashmir; cultivated by marginal to large farmers and consumed by almost every household. Moreover, it is interesting to know that despite being the water-loving crop as thought earlier, rice is also being cultivated in the upland areas, where water availability is a major constraint. As per the latest government estimates, rice is cultivated in 43 million hectares of arable land in almost all the Indian states and during the year 2020-2021 and non-basmati rice has emerged as the important item exported by India, sharing about one-fourth of the total exports. The major trade of the non-basmati rice took place between the global south like India and Timor-Leste, Puerto Rico, Brazil, Papua New Guinea, Zimbabwe, Burundi, Eswatini, Myanmar and Nicaragua (PIB 2021), however, India exports rice to more than 75 countries across the globe. Thus, the rice crop has much significance not only for the food security of India alone but for other countries in the world too. As per the latest Climate Risk Index (CRI)

2021 report, India ranks seventh in 2019 CRI which was 20th in for 2000-2019 CRI (Eckstein et al. 2021) which indicates the increase in the level of climatic risk with India. In this context, the impacts and future implications of climate change on rice farming holds much significance.

In this chapter, we have emphasized the theoretical understanding of the economics of climate change with special reference to agriculture and reviewed studies to gather shreds of evidence supporting the theory. The chapter is organised into six sections. The first section discusses the economics of climate change concerning agriculture while the second section reports about the cost of climate change. In the third section, we reviewed the impact studies of climate change on rice. In the fourth section, we have discussed potential socioeconomic impacts on rice farming based on the physical, temporal, spatial and environmental impacts. Finally, we proposed the adaptation and mitigation options that can be promoted among the farmers to deal with the adverse impacts of climate change.

2. Economics of climate change

After the mid 20th century, anthropogenic causes overshadowed the natural causes of climate change. Insights into global carbon emission estimates led one to understand the positive linkage between the level of economic development and carbon emission. Further, the economic decision (production, consumption, investment) of one economic agent (producer or consumer) often affect the other economic agent not involved in the transactions and are referred to as externalities by the economists when they became sufficiently large. So like others, anthropogenic climate change is one of the externalities. To keep this discussion simple, we considered two classes of economic agents in society. One belongs to the farming class and the other belongs to the non-farming/ industrial class. Further, the two classes are not mutually exclusive as both of them releases greenhouse gases (GHGs) into the atmosphere and consequently gain/loss from it. However, the difference in the intensity of release in terms of CO_2 equivalent per unit time led us to categorize them into two groups. This assumption can be extrapolated to the global north and global south. Additionally, those who release GHGs into the atmosphere (non-farming group in our discussion) are the generator of climate change. These GHGs generators inflict the social cost spatially (on another group) and temporally (on future generations) as other groups' economic activities are closely linked with climatic variables and some of these GHGs are there to stay for a long in the atmosphere. Although the CO_2 fertilization effect has a positive effect on crop output (positive externality), it is outweighed by the negative externality caused by the rise in temperature, floods, droughts and other extreme climatic events like heat waves, cyclones, tsunamis, hailstorms, etc. Hence, climate change inflicts a net social cost on the farming group. Although the cost imposed at time "t" has a limited effect on the crop output at the same time "t", one cannot overlook the impact of this cost at "t+i" (i=1 to n) period as some of the GHGs are going to exist in the atmosphere for a long time. Under the assumption of continued economic development and residual nature of GHGs in the atmosphere the social cost curve would be upward sloping however the steepness of the curve is a function of the change in the stocks of GHGs in the atmosphere. We also assume that the global climate actions and technological progress (in the renewable energy sector) would slow down the incremental changes in the stocks of atmospheric GHGs however the social cost inflicted by the climate change would not follow a similar path as that of incremental emission curve due to the residual nature of GHGs.

To begin our discussion on the economics of climate change, we start with the environmental Kuznet curve (EKC), which indicates an inverted U shape relationship between the level of economic development and environmental degradation (Fig. 1a). In the early stages of economic growth, the level of economic degradation exhibits a proportionate relationship with an increase in per capita income mostly because of an increase in pollution due to emphasis on carbonaceous fuels like coal. However, the economic growth and technological progress in the society is accompanied by progressive use of cleaner fuels and gradually switching towards renewable energy resources and releases lesser GHGs at later stages (Fig. 1b). This shift in fuel consumption led to the downward turning of EKC as there is a lesser incremental build-up of stocks of atmospheric GHG. As a result, the environment rejuvenates and degradation also decreases. As the lagged carbon emission of the "t-i" (i=1 to n) period has already built up stocks of GHGs in the atmosphere and stayed there for long, the abatement costs are not going to come down proportionately, corresponding to the period of decline of emission. However, cleaner fuels and renewable energy consumption would lead to a decrease in the steepness of the abatement cost curve (Fig. 1c). Studies have revealed the sensitivity of the total factor productivity of the crop to climatic variabilities (Zong et al. 2019; Chancellor et al. 2021). As a result of higher marginal abatement cost to be incurred by the farmer (in terms of additional input consumption, land reclamation measures, a surge in the cost of input application, etc.), the net returns from a particular crop enterprise would diminish for the farmer. This nexus of costs and net returns provokes resource reallocation among the most competing alternative. However, the resource allocation among new alternatives may not be abrupt, rather it would be a gradual process. As a result, the output supply from a particular enterprise would decline and the supply curve would shift leftwards (Fig. 1d).

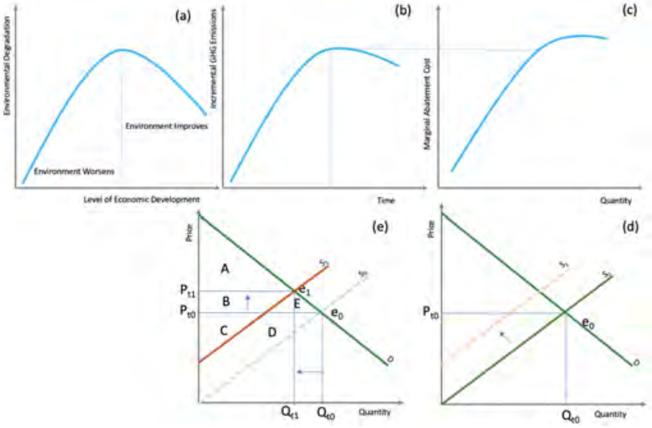

Figure 1. Economic impacts of climate change on the agriculture sector

Box 1. Summary of economic impacts of climate change on market demand and supply

Climate change would lead to:

1. Decrease in market supply, thus supply shocks,
2. Increase in price of agricultural commodities, hence inflation,
3. Erosion of consumer surplus, hence few consumers would leave the market,
4. Erosion of producer surplus force them to decrease the production and pushes some of them to leave the market
5. Increase in dead weight loss (a loss in economic efficiency) as a result of disequilibrium of supply and demand,
6. Market disequilibrium can provoke resource reallocation in favor of most competing alternatives.

Assuming the demand to remain constant, as a result of a leftward shift in the supply curve, the market equilibrium would shifts from e_0 to e_1, equilibrium quantity would shift from Q_{t0} to Q_{t1} and the equilibrium price would increase by P_{t1} minus P_{t0}. Further, the change in market equilibrium would reallocate total market surplus (producer surplus plus consumer surplus) among producers and consumers. It is evident from the above figure (Fig. 1e) that, originally the total market share was A+B+E (Consumer surplus) plus C+D (Producer surplus) which later adjusted to A (Consumer surplus) plus B+C (Producer surplus) due to climate change-induced adjustment of the market forces. Moreover, the adjusted market surplus due to climate change (A+B+C) is smaller than the original market surplus (A+B+C+D+E) (Fig. 1e). The worst consequence of the changes in marketable surplus may force some of the vulnerable players with limited adaptation capacity to exit the market, thus rendering them unemployed and pushing towards poverty. However, it is more likely to observe frictional unemployment when limited adaptation capacities coupled with lag in decision making about the future. Alternatively, one may also observe forced enterprise diversification as a consequence of climate change.

3. Impact of climate change on Indian agriculture

Dryland regions and populations dependent on agriculture-based livelihoods are disproportionately at a higher risk to climate variability (IPCC 2018). India with more than 50 per cent of its population engaged in agricultural enterprises are therefore vulnerable to the consequences of climate change. Most of the studies have attempted to trace the impact of variability in temperature, rainfall and CO_2 concentration on crop yield, crop growth and soil fertility, insects and weed population. In the Indian context, impact studies have not only restricted themselves to the physical/agronomic impacts but have ventured into the spatial and temporal impacts, socioeconomic and environmental impacts too. Here, we have compiled the impacts of climate change relevant to the agricultural sector in general and crops in particular. Table 1 summarises the diverse impacts of climate change.

Table 1. Summary of some of the impact studies of climate change on agriculture

A)	**PHYSICAL IMPACTS**			
S. No.	**Dependent variable**	**Explanatory variable**	**Impacts**	**Author(s)**
1.	Crop growth	Elevated CO_2 concentration	• Increase in photosynthetic rate, light-use efficiency and water-use efficiency. • Decrease in transpiration and stomatal conductance	Drake et al. (1997)
2.	Crop yield	Elevated CO_2 concentration	• Increase in the biological and economic yield of crops.	Singh et al. (2010)
3.	Crop yield and crop growth	Elevated temperature	• Biomass and yield tend to decline with increasing temperature • Early maturity of crop/ shortened crop duration, enhance respiration and reduce the time for radiation interception.	Rawson et al. (1995); Chakrabarti et al. (2012)
4.	Crop yield and grain quality	Elevated temperature and solar radiation	• Increase in temperature even by 1°C or 2°C, significantly reducing the grain yield. • The decline in grain quality was influenced by increased night temperature. • Solar radiation has a positive effect on yield and aroma.	Anand et al. (2012)
5.	Soil fertility	Temperature, rainfall and CO_2	• Climate change is expected to bring down the soil carbon level. However, nitrogen mineralization would increase with the increase in soil temperature but its availability would decrease due to denitrification and volatilization losses.	Chakrabarti et al. (2012)
6.	Pest population	Temperature, rainfall and CO_2	• Pest severity and thus the pest-induced yield losses would decline with global warming.	Subhash Chander(2012)
7.	Weed population	Elevated CO_2 and temperature	• With elevated CO2 levels, higher growth of rhizomes and other storage organs in perennial weeds, higher seed production in annual weeds, etc. would be observed due to enhanced photosynthetic efficiency.	Das et al. (2012)

B)	**TEMPORAL IMPACTS**		
S. No.	**Season**	**Impacts**	**Author (s)**
1.	***Kharif***	• Agriculture may become riskier due to increased climatic variability and pest incidence and virulence.	Aggarwal (2003)
		• Extreme temperature (Elevated temperature) and extreme rainfall (rainfall deficit) shocks would decline the average *Kharif* yield of crops by 4.0 and 12.8 per cent; irrigated *Kharif* crops by 2.7 and 6.2 per cent and unirrigated *Kharif*crops by 7.0 and 14.7 per cent, respectively.	GoI(2017)
2.	***Rabi***	• Production of crops is more seriously threatened due to projections of a larger increase in temperatures and uncertainties in rainfall.	Aggarwal (2003)
		• Extreme temperature (Elevated temperature) and extreme rainfall (rainfall deficit) shocks would decline the average *rabi* yield of crops by 4.7 and 6.7 per cent; irrigated *rabi* crops by 3.0 and 4.1 per cent and unirrigated *rabi* crops by 7.6 and 8.6 per cent, respectively.	GoI(2017)

C)	**SPATIAL IMPACTS**		
S. No.	**Regions**	**Impacts**	**Author (s)**
1.	North-West India	For rice, the CO_2 fertilization effect is not sufficient enough to offset the negative impact of higher temperatures under the changed climatic conditions.	Lal et al. (1996)
2.	Central and Southern India	Central and southern Indian regions, which are already warm at present, may be more seriously affected than northern India.	Aggarwal (2003)
3.	Indo-Gangetic plains	Near term impact of climate change would not be severe, however, extreme climatic events could result in discernible effects on agricultural production and productivity.	Singh et al. (2019)
4.	Fourteen agro-climatic zones (ACZs) of India	Progressive reduction in most of the crop yields, but the magnitude of impacts and projections vary by ACZs	Singh et al. (2020)
5.	Assam	The forced migration of rural people towards urban centres as floods poses erosion risks to farmlands.	Das (2015)

6.	Northeast	Climate change has an overall negative impact on the rice yield in north-eastern India.	GoI(2011)
7.	Kerala	For every degree rise in temperature, rice yield decline by 6 per cent.	Saseendran et al. (2000)
8.	Punjab	The climate change and fluctuations experienced in Punjab over the past couple of decades has reduced rice and wheat yields and consequently national food security.	Kumar and Sidana(2019)
D)	**ENVIRONMENTAL IMPACTS**		
S. No.	**Factors of crop production**	**Impacts**	**Author (s)**
1.	Weather phenomenon	Glacial retreat in the Hindu Kush Himalayas, compounding effects of sea-level rise, intense tropical cyclones leading to flooding, erratic monsoon, intense heat stress are likely to impact India in recent years.	IPCC (2021)
2.	Water for irrigation	Water for agricultural production in the river basins of the Indus, Ganges and Brahmaputra will reduce further.	The World Bank (2013)
3.	Arable land	Regions with higher latitude like Russia and China may gain in the arable area while tropical and subtropical regions of the world like India may lose 2-4 per cent of its arable land.	Zhang and Cai (2011)
4.	Soil fertility	Negative impacts of climate change on soil fertility and mineral nutrition of crops will far exceed beneficial effects	Clair and Lynch (2010)
5.	Agricultural biodiversity	Climate change is likely to be an additional threat to agricultural biodiversity, increasing genetic erosion of landraces and threatening wild species, including crop wild relatives	Jarvis et al. (2008)

E)	SOCIOECONOMIC IMPACTS		
S. No.	**Socioeconomic variable**	**Impacts**	**Author (s)**
1.	Farm income	• In a year with a temperature higher by 1°C and rainfall deficit by 100 mm from the average rainfall, average farm revenue during *Kharif* would decline by 4.3 and 13.7 per cent while the farm revenue during *rabi* would decline by 4.1 and 5.5 per cent, respectively. • With no policy response under IPCC climate change projections for India, farm income is estimated to be lost by 15-18 per cent on an average and 20-25 per cent for the unirrigated area, which is at the current level of income would translate into more than Rs. 3600 per median farm household.	GoI(2017)
	Farm Income	• Farm income would decline as a consequence of climate change.	Singh et al. (2018)
2.	Unemployment, rural migration and indebtedness among the farmers	• Climate change would lead to an increase in farm unemployment, rural migration and indebtedness among farmers.	
3.	Food prices, poverty, rural-urban income parity and supply shocks	• May increase due to climate change	Kumar and Parikh (2001)
4.	Consumer utility	• May decline as a result of climate change	

F)	EFFECT ON GRAIN QUALITY			
S. N.	**Causal factor**	**Quality indicator**	**Effects**	**Author (s)**
1.	Elevated CO_2 concentration	Seed mass	Increase in seed mass owing to enhanced availability of plant assimilates.	Jablonski et al. (2002)
		Seed width	No effect on seed width at 610 ppm of CO_2, however CO_2 elevation of 760 ppm cause an increase in grain width.	Lamichaney et al. (2019)

		Total soluble sugar (TSS) content	At an elevated CO_2 level of 510, 610 and 720ppm, the TSS content of rice grains was found to decrease than normal.	Lamichaney et al. (2019)
		Head rice recovery (HRR)	Incomplete grain filling under elevated CO_2 leads to softer grains and consequently reduced HRR.	Liu et al. (2017)
		Grain colour	Increase in the whiteness of brown as well as white rice	Terao et al. (2005)
		Amylose content	At elevated CO_2 of around 550 ppm, amylose content decreased from approximately 25% to 6, 19, and 16% for the white rice, bran, and brown rice respectively.	Guofo et al. (2014)
		Protein content	An increase in atmospheric CO_2 concentration is negatively correlated to the protein content of the grains.	Yang et al. (2007)
		Dietary fibres	Elevation in CO_2 level caused a 2-fold increase in dietary fibres content of both brown rice and bran respectively.	Guofo et al. (2014)
2.	Elevated Temperature	Gelatinization Temperature	Grains exposed to high temperature during their maturity results in starch content with higher GT which increases the cooking time	Krisnan et al. (2011)
		Chalkiness of grain	Compared with normal temperature, rice chalky rate (36.5%), chalky area (103.3%), and chalkiness (176.4%) were significantly increased under the field warming (temperature increased by 2.8°C).	Liu et al. (2021)
		Grain starch content	Amylopectin content increased whereas amylose content reduced thereby changing the proportion of amylopectin/amylose in rice grains.	Liu et al. (2021)
		Grain protein content	Glutenin content increased significantly however prolamin content decreased at elevated temperatures.	Liu et al. (2021)

Source: Authors' compilation

Economists also tried to estimate the costs of climate change. As per a report from the Deloitte Economics Institute, climate change could cost India $35 trillion as economic potential lost over the next 50 years, if left unchecked (Masterson 2021). An analysis by Council on Energy, Environment and Water (CEEW) suggests that more than 75 per cent of Indian districts are exposed to extreme climate events and it pegs direct costs of India's lack of disaster preparedness in the last two decades at $179.5 billion (Economic Times 2021). Yet another report by a London-based global think tank Overseas Development Institute pegs lose to India around 3 to 10 per cent of its GDP annually by 2100 and a tentative rise in its poverty rate by 3.5 per cent in 2040 because of climate change (Roy 2021). Additionally, the economic survey (2018) tags annual loss of US$ 9-10 billion due to the adverse effects of climate change (As cited by Srinivasa Rao et al. 2019). Estimates of crop area affected due to natural extreme events in India shows that about one-third of gross cropped area (197.05 m ha) (the base year 2015-16) has been affected in just the initial eighteen years of the 21st century (ICAR 2020). Further, from 1876 to 2009, 38 years had been declared as drought years in India, out of which the intensity of droughts after 1975 was mostly moderate to severe category (FAI 2016-17). The average departure of rainfall from normal in the last two decades stood at -1.87 (between 1993-2002) and -5.42 (2003-2013) per cent, respectively. During the period 1953 to 2015, 34 years have witnessed flooding/heavy rain in different parts of India, which has cumulatively damaged 236.67 million hectares of cropped area and inflicted a penalty of Rs. 84.89 billion due to damage to the crops (GoI 2016). Though the damage being over-estimated (as derived by summing overall damage to the crop area between different periods and also the database does not mention their spatial distribution), it provides a direction for future actions. It is worth mentioning that the degree of impact of climate change on agriculture can vary based on latitude, level of socioeconomic development, type of agricultural enterprise, crops grown, technological endowments and other factors. Moreover, climate change also inflicts some penalties on the farmers cultivating field crops like yield penalty, cost penalty, and income penalty. Yield penalty is the consequence of area and production penalty as climate change induces resource degradation (like increase in soil salinity due to seawater encroachment and inundation and losses due to resurgence of pests and diseases under changing climatic conditions). Cost penalty can be due to surging variable cost of production (like the incremental cost of pumping irrigation water due to decline in the groundwater table, higher input costs due to land degradation and pest and disease attack, etc.) plus abatement cost of environmental degradation (like digging farm pond, taking agro-forestry for increased carbon sequestration, change in cropping pattern etc.). The complexity of the income penalty lies in the fact that on the one hand, the higher prices of agricultural products will benefit the farmers but these benefits can be pulled down by the surging costs and declining production.

4. Socioeconomic impacts on rice farming

Although Table 1 shows the results of earlier studies on socioeconomic impacts, we base our discussion on physical, temporal, spatial and environmental impacts and discussed how these impacts are going to socioeconomically impact rice stakeholders. Globally, studies have revealed climate change as one of the most significant and long-term obstacles in attaining sustainable growth in rice production (Adams et al. 1998; Wassmann and Dobermann 2007; IFPRI 2010; Vaghefi et al. 2001). Simulation studies across the world have tried to establish the relation between climate variables (variability in temperature, rainfall, CO_2 concentration and solar radiation) and rice yield and projected the medium to long term impacts of this variability on rice yield. It is well established that the CO_2 fertilization effect, precipitation and solar radiation, positively impact the paddy yield while yield decline at elevated temperature. However, variability in these variables may have negative effects on the yields. The findings of Lal et al. (1996) are relevant in this context which reports that the CO_2 fertilization effect would not be able to offset the negative impact on rice yields due to higher temperature under the changed climatic conditions. A similar conclusion was also drawn by Singh et al. (2019) in their study in Indo-Gangetic plains of India on rice and wheat crops which reported that the impact of rainfall was not sufficient enough to counterbalance the combined impacts of maximum and minimum temperature on crop yield. Hung et al. (2018) have reported that with an increase in temperature, rice yield decreases in most of the Indian states except in the states with high altitude; precipitation and solar radiation favours *Kharif* yield rather than the *rabi* yield and high precipitation impedes the growth of yield and rice cultivation areas during the rainy season at low temperature with scanty solar radiation. Moreover, Fitzgerald and Resurreccion (2009) and Kim et al. (2011) disclosed that the temperature beyond the critical threshold not only decrease the growth duration of rice crop but also increase the spikelet sterility, decreasing grain filling duration, enhancing respiratory losses and lowering yield and grain quality. Similar results were also reported by Peng et al. (2004) and Welch et al. (2010) who disclosed that the high night temperature of 1°C above the critical temperature (24°C) reduce the yield and biomass by 10 per cent. Weerakoon et al. (2008) have investigated the effect of the interaction of temperature and relative humidity (RH) on rice yield and reported that high RH with moderate to high temperature has higher negative effects on rice yield than with lower RH. The impact of the flood on rice yield has been captured by Mohanty et al. (2013) under three different scenarios namely, i) complete submergence, ii) partial submergence, and iii) water logging in direct-seeded rice (DSR). Their result reveals that complete submergence of paddy plants induce plant mortality after a few days of submergence while partial submergence triggers yield loss and water lodging in DSR impair seed germination. Rice is moderately salt-sensitive with a threshold electrical conductivity of 3 dsm^{-1} (Maas and Hoffman 1977), however, it is relatively more tolerant to salinity during germination, active tillering and maturity but sensitive during early vegetative and reproductive stage (Moradi et al. 2003; Singh et al. 2008). The findings of Widawsky and O'Toole (1990) are alarming for rice farming in the upland areas as they reported that drought accounts for approximately 30 per cent of average annual yield loss to rice crops in upland areas. Similarly, estimates of losses due to flash floods by IRRI (2010) are much relevant in a period of extreme climatic events which reported that rice production losses in Bangladesh and India due to flash floods account for 4 million tonnes per year which could have fed 30 million people.

Extending the economic analysis as discussed in the earlier section to the impacts of different climatic variables on rice crops would be crucial to delineate the socioeconomic impacts of climate change on rice farming. To achieve this, we used the marketable surplus approach to rice farming. To begin with, we have to make a few assumptions, like i) the entire world represents a closed economy which allows international trade in a commodity (say rice for our discussion) but no interplanetary trade, ii) cost of climate change would be inflicted on the farmers only after the base period (just for better understanding of the impacts), iii) cost of climate change overweigh the benefits, and iv) during the base period T_0, demand for rice and supply of rice to be represented by demand curve "D" and supply curve by S_0 (Fig. 2).

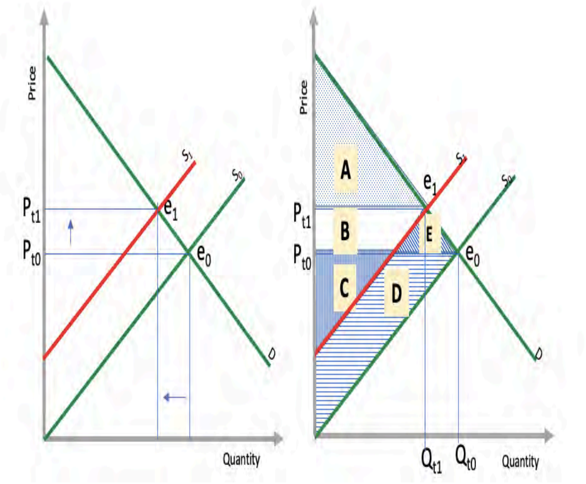

Figure 2. Impact of climate change on rice farming through the marketable surplus framework

During T_0, both the demand and supply curve intersects at equilibrium point e_0 and clears the market at quantity Q_{t0} and price P_{t0}. During the base year, the total marketable surplus in the rice market was A+B+C+D+E of which A+B+E comprise consumer surplus while C+D comprises producer surplus. In subsequent years, the physical and environmental impacts of climate change would impose some costs on the farmers. Say this cost penalty to be the abatement cost for mitigation and adoption for the impacts of climate change. In other words, the farmer has to incur additional costs directly for crop production in the form of variable as well as fixed costs. Variable costs include additional irrigation cost due to increased expenditure on energy per irrigation because of depleting groundwater table and the marginal cost of an increase in the number of irrigations; incremental cost of pest management due to resurgence of new pests; incremental cost of weed management; increased expenditure on chemical fertilizer like urea, etc.

Contrary to it, the cost of water harvesting and storage (construction of farm pond and other water harvesting structures), cost of carbon sequestration (by taking up agroforestry plantation on the farm) and cost of changing cropping pattern, etc. would be the additional fixed cost which a future farmer has to incur directly. Also, the yield loss due to a variety of biotic and abiotic stresses and loss in the quality of the paddy would fetch lesser returns to the farmers. The differential impacts over the base period can be called the indirect cost of climate change which a farmer has to incur. Further, the land degradation due to seawater intrusion, the salinity of soils, flash floods and cyclones are expected to carve out the vulnerable lands out of arable land, thereby declining the arable land under crop. Additionally, the uncertainty of climatic variables would impair farmers' investment capacities. This argument is quite relevant for India where the majority of landholdings are marginal and small with the increasing trend for fragmentation of farm holdings and having monthly income between Rs. 6000-7000 only. Thus, an increase in costs and uncertainty would decline the supply of rice in the most pessimistic scenario (i.e., without technological, institutional and political actions against climate change). As a result, the original supply curve S_{t0} would shift towards left and the market equilibrium also shifts towards e_1 which clears the market at lesser quantity Q_{t1} ($Q_{t1}<Q_{t0}$) and higher market price for paddy P_{t1} ($P_{t1}>P_{t0}$). Subsequently, the total marketable surplus also decreases from A+B+C+D+E to A+B+C at which the producer and consumer surplus are B+C and A, respectively. It is very clear from the readjustment of total marketable surplus is that the producer and consumer surplus both decline with climate change. Hence, the consumer has to pay an extra Rupee for the same quantity of rice procured in the base period T_0. However, it doesn't mean that the producers are better off due to price increase as a decline in the area due to land degradation may nullify this effect. Further, the decline in producer surplus from the paddy would invoke farmers to allocate their limited resources among the most competing end and forcefully reallocate the resources for more favourable crops and thereby exit the rice enterprise. Hence, one can observe forced crop diversification as a consequence of climate change in days to come. Further, climate change may lead to a surge in the household food consumption expenditure and higher household expenditure on mitigation and adaptation, thereby eroding the savings and diminishing the prospects of private investments. However, the impact on savings would vary based on the socioeconomic status and income flow of the family. On the other hand, declining profits for the farmer may likely grip them under the clutches of indebtedness and increase poverty among farm households. Further, supply shocks and income loss may potentially push the vulnerable under food insecurity and would pose serious challenges to the attainment of SDGs.

However, the impacts of climate change are not one-sided only. In Figure 3, we have depicted the potential socioeconomic impacts of climate change on rice farming. Crop duration may get shortened due to the early maturity of crop hence climate change opens new opportunities for agricultural intensification subjected to the moisture availability and cost of irrigation. Further, shorter duration may reduce the number of irrigations to the crop but, spikelet sterility and subsequent yield loss may nullify these gains.

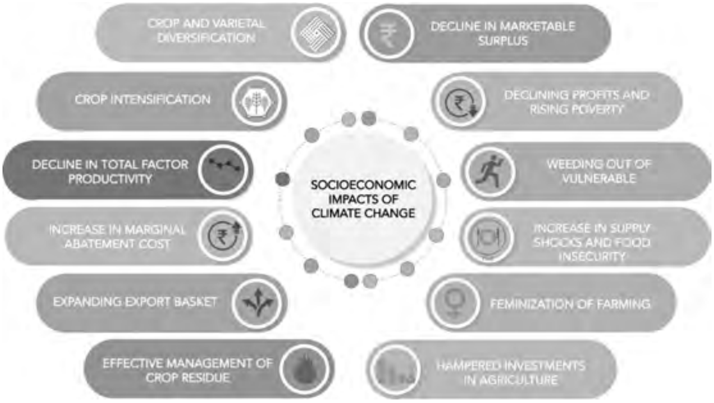

Figure 3. Potential socio-economic impacts of climate change on rice farming (Source: Author's elaboration)

In the rice-wheat cropping system of north-western India where paddy stubble burning is a major issue for the last two decades mainly due to the limited time window between the *harvesting of paddy* and sowing of wheat crops. Climate change may open opportunities for effective management of paddy straw as the time lag between *Kharif* and *rabi* crops may get widened. Crop diversification is also another dimension that may get a boost with climate change; however, the development of short duration terminal heat stress-tolerant varieties would encourage varietal diversification. If India could able to sustain its surplus rice production due to its technological improvements, its export basket of non-basmati rice can be diversified, provided that the trade policy favours international trade. However, India needs to enhance the water use efficiency of its rice crop to put a restraint on exporting its groundwater. Studies have also indicated that climate change would force rural emigration (Hasan and Tularam 2018; Hari et al. 2021) and promote feminization of agriculture (PIB 2018), which means the overburdened agricultural sector will be decongested which may add to the increase in the marginal productivity of workforce engaged. However, the increase in the burden of agriculture without proportionate change in property rights of resources in their favour may imbalance gender parity in agriculture. Additionally, efforts are required to focus on the development of gender-friendly agricultural practices and tools.

5. Adaptation and mitigation alternatives and government supports

Appropriateness of any adaptation or mitigation strategy for climate change varies based on the degree of vulnerability, exposure and current status of the ecosystem fragility. There may not be an exhaustive list of full proof strategies which would be effective against any adverse event. However, scientific research provides a bunch of some promising strategies which can be deployed under certain circumstances to mitigate the adverse effects of climate change or to sustain the production activities without incurring a significant loss. Srinivasa Rao et al. (2016) and Srinivasa Rao et al. (2019) have meticulously discussed the concepts, processes, technologies and institutions of the climate-resilient village which provides a comprehensive ground-level strategy to deal with climate change (Fig. 4). Also, under the scenario of increasing climatic risk, the importance of reliable and timely weather forecast, institutionalization of early warning system (EWS) and crop insurance can prove to be an effective tool to averse the losses. District AgroMet Units (DAMU) under *Gramin Krishi Mausam Sewa* is a worthy project which strengthens vulnerable farmers in taking timely decisions to deal with climatic variabilities. *Pradhan Mantri Fasal Bima Yojana* (PMFBY) on the other hand provides the safety net for the farmer in events of losses due to weather extremes. The government needs to invest in the creation of common property resources like village ponds and subsidize cost in the creation of such resources which indirectly adds to social benefits. For example, an individual farm pond may prove to safeguard the farmer's crop from incidence of moisture stress directly, but the benefits of groundwater recharge would percolate the benefits to the neighbour farmers well. The creation and maintenance of community resources like village ponds, social forests and other afforestation programmes under the *Mahatma Gandhi National Rural Employment Guarantee* (MGNREG) programme is an appreciable step in this direction. Moreover the traditional water storage structures like *kul* in Jammu and Kashmir and Himachal Pradesh, *ahar pynes* in Bihar, *zabo* in Nagaland, *kundis* in Rajasthan, *virdas* in Gujarat, *eri* in Tamil Nadu, etc. would help in shielding the crops from water stress. Scientists have advocated for crop diversification and in the Indian context, Pathak et al. (2020) have advocated for a reduction in paddy area from unsuitable areas like uplands which also calls for crop diversification.

Figure 4. Climate change adaptation technologies with co-benefits of mitigation (Source: Srinivasa Rao et al. 2020)

Box 2. Key socioeconomic implications of climate change on rice
Socioeconomic impacts of climate change on rice sector include:

1. With increasing climatic variabilities, paddy yield is expected to decline in future which may lead to decline in supply of rice in the market (Decrease in availability).
2. Declining supply of paddy in the market would surge the price of rice and rice-based products in the market and thereby erode the consumer surplus and make rice grain inaccessible to the poor consumers (Increase in inaccessibility),
3. Erosion of consumer surplus may force the vulnerable/price sensitive/poor consumers to shift their consumer expenditure from rice to cheaper alternatives of calorie (Shift in consumption pattern),
4. Gains accrued due to increase in the price of paddy would not be sufficient enough to compensate the losses accrued to the reduction in production, hence overall producer surplus may decline with climatic variability,
5. Declining producer surplus may force the marginal and small farmers to exit the market (weeding out of inefficient small and marginal farmers),
6. Decline in net profits of the paddy farmers may force them to undertake varietal replacement or crop diversification or both (Forced varietal and crop diversification),
7. Resource reallocation in the farm in favor of more climate resilient varieties and crops,
8. If India can sustain its rice production with climate change, export basket of rice crop especially the non-basmati rice is expected to diversify as many of the rice producing and consuming countries are expected to face the production shocks and food security crisis (Diversification of export destination for non-basmati rice),
9. Increase in the abatement cost (cost of reducing environmental negativity) to the farmers (incremental cost of seeds of climate smart varieties, cost of water harvesting and storage due to construction of farm pond, cost of changing cropping pattern etc.)
10. Vulnerable population may be pushed in food insecurity trap,
11. Declining farm income from paddy may affect the investments in paddy crop by the farmers, however investments in mitigation and adaptation technology may increase.

However, it is interesting to understand that if crop diversification is not taken voluntary, nature will ensure that it would be taken up forcibly. The incentivization policy of the state of Chhattisgarh and Haryana for not taking up paddy and diversification to other crops is a stride in the direction of imposing crop diversification. Development of advanced tools in biotechnology like Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) also opens new opportunities for the development of climate-smart rice varieties, which are tolerant to various abiotic and biotic stresses. Further, breeding efforts should be put to develop the rice variety, which can tolerate submergence due to flash flooding and heat stress due to drought. In this direction, the development of CR Dhan 801 and CR Dhan 802 rice varieties by ICAR-National Rice Research Institute (Pathak et al. 2019) is a noteworthy contribution. Coastal flooding and intrusion of saline seawater can be checked by modifying the *Sorjan* (in Bangladesh)

(Clough et al. 2001)/ *Sawah Surjan* (in Indonesia) (Rijanta 2018) system as per the Indian needs. The *Srojan* system not only ensures crop diversification but checks brackish and saline water to encroach inside the agricultural land. Further, scaling up of agronomic measures like mid-season drainage or alternate wetting and drying (AWD) of rice fields would put check on the wastage of water in paddy production. Direct seeded rice (DSR) also ensures reduced emission from paddy fields, however, management of weed is the major challenge associated with this method. Integrated weed management in DSR and extension efforts in popularising this technology can be a much-needed step for mitigating the ill effects of climate change. In this connection, Majumdar et al. (2019) has advocated the dissemination of climate-smart technologies to the vulnerable based on socioeconomic attributes. Apart from weeds, poor germination in water lodging conditions in DSR is another challenge faced by the farmers. Thus, the development of cultivars with early seedling vigour in anaerobic conditions can be a game-changer for small and marginal farmers. Monitoring and forecasting of climate variability, disease and pest incidences although in practice can be boosted up by integrating the advances in new technologies like artificial intelligence (AI), big data and machine learning (ML). At the farm level, strategies like change in planting schedules, irrigation scheduling, harvest scheduling, varietal replacement and enterprise diversification can be some of the alternatives to adapt to changing climate change.

6. Conclusion

Climate change is not only having a direct impact on the physical indicators (growth and yield) of rice crop but indirectly affects the resource allocation and influence the income, cost, surplus, poverty, hunger etc. The environmental, physical, spatial and temporal impacts of climate change on rice crops may lead to some of the socioeconomic outcomes. These include an increase in the abatement cost for the farmers, decline in the total marketable surplus from rice farming, threat to food security and attainment of sustainable development goals due to food supply shocks, forced crop diversification etc. India, being at the fulcrum of the global rice market, need to undertake the appropriate steps to mitigate the adverse impacts of climate change and protect its vulnerable farming class from the an of climate change. Additionally, for eastern India, where rice is synonymous to livelihood form both the demand and supply point of view, the socioeconomic implications of climate change calls for investments in climate resilient technologies and sustainable crop cultivation practices.

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Chapter 23

Social Vulnerability to Climate Change: How to Develop an Inclusive Framework

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Abstract

Climate change is inevitable, happening now and at a faster speed than expected. Certain regions, sections of society, systems are affected more by these changes than others. This can be attributed to their vulnerability towards climate change. Vulnerability indicates a state that is susceptible to harm when exposed to stress due to environmental or social changes and the absence of adaptive capacity. But, the core concept of vulnerability has been changing in different assessment reports of IPCC. Initially, vulnerability was conceptualized as the function of exposure, sensitivity and adaptive capacity. But, in the Fifth Assessment Report (AR5), 'exposure' has been disassociated from vulnerability. Among the different approaches to assess vulnerability, the most popular and commonly used in recent years is the indicator- based approach as it is a bottom-up approach. A common framework for development of 'Social Vulnerability Index' has been discussed in this chapter. The steps include selection of a wide range of indicators followed by Principal Component Analysis for their identification. Weights of indicators can be calculated using Analytical Hierarchy Process. Then, the selected indicators will be normalized and combined by a weighted linear combination to form an index. Finally, spatial analytical tools like Global Moran's I and Getis-Ord Gi* can be applied to identify the vulnerable hotspots. This is inclusive framework can be used to analyze social vulnerability to climate change for the agrarian community in any agro-ecosystem of the country.

Keywords: Climate Change, Index, Social Vulnerability, Vulnerability assessment

1. Introduction

Climate change is no more a topic that needs introduction. It has been established through numerous studies and reports that the global climate is changing and adversely affecting life on the planet. Agriculture is one of the most important sectors that is at the mercy on climatic factors. It is highly susceptible to be adversely affected in case of climate change. In case of extreme events like droughts and floods, there is extensive impact on agriculture. Climate change will be the single most contributor of changes in land and water resources in terms of availability and usage, disease pest incidences, etc. Certain regions, sections of society, systems are affected more by these changes than others. This can be attributed to their vulnerability towards climate change. In order to cope up with climate change, the most suitable measure is to adapt to the changing scenario. For identifying target groups and developing appropriate adaptive measures, we need to ensure and order vulnerable groups. This can be achieved through vulnerability assessment.

Vulnerability assessment plays a link between assessing climate change impacts and planning development for present and future (Downing et al., 2005). Vulnerability assessments are done to estimate the potential damage and loss from a certain hazard or disaster event. These studies help us to understand the human-environment relationship which aids in making informed and relevant adaptation decisions. Adaptation policies based on vulnerability assessments have been found to be successful and effective as they are derived from the study of biophysical-socio-economic interactions which are the root of vulnerability of a system.

The chapter deals with interpretations of vulnerability, different approaches and methods of vulnerability assessment, general conceptual framework for vulnerability assessment in the following sections. In order to provide a conceptual framework for the assessment of climate-change related vulnerability, the chapter includes an overall review of different existing definitions of vulnerability with respect to climate change and approaches to vulnerability assessment.

2. The concept of vulnerability

The origin of the word ‘Vulnerability’ can be traced to the Latin term *vulnus* which means ‘a wound’, and *vulnerare* which means, ‘to wound’. The word vulnerable is especially derived from the term *vulnerabilis* which is a Late Latin word used by the Romans to describe the state of a soldier lying wounded in the battlefield. It indicates, already injured therefore at a risk from further attack. This description of the term vulnerability is relevant in present context as it provides an insight to vulnerability being defined primarily by the prior damage (the existing wound) and not by the future stress (any further attack). By analogy, then, the vulnerability of any individual or social grouping to some particular form of natural hazard is determined primarily by their existent state, that is, by their capacity to respond to that hazard, rather than by what may or may not happen in the future. Blaikie et al. (1994) defined vulnerability in terms of human dimensions, separating the biophysical and social context as, "the ability to anticipate, cope with, resist, and recover from the impact of a natural hazard".

Vulnerability, in general, is understood as the potential for loss. Vulnerability indicates a state that is susceptible to harm when exposed to stress due to environmental or social changes and the absence of adaptive capacity (Adger, 2006). It has been defined as susceptibility of a system to disruptions as a result of exposure to perturbations, sensitivity to perturbation and the capacity to adapt (Nelson et al. 2010). In addition to the susceptible aspect of vulnerability, other aspects of vulnerability have also been highlighted by different scholars. For example, Cutter et al. (1996) pointed out that three distinct themes can be observed in vulnerability. According to her other definitions of vulnerability is either (i) vulnerability as risk/hazard exposure or (ii) vulnerability as social response and (iii) vulnerability of a place. Hence, it has been well said that a variety of concepts and elements are encompassed within vulnerability which includes sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

2.1 Vulnerability and social vulnerability: Basic foundations and delineations

Vulnerability is multi-dimensional and multi-sectoral subject. Hence it is defined differently according to the purpose. As mentioned in the previous section it has been found that divergent definitions of vulnerability exist. This is due to the different epistemological orientation (Cutter *et al*., 1996). The most widely accepted and commonly used definition is that given by that of the Intergovernmental Panel on Climate Change (IPCC). It is considered to be the leading scientific international body for the assessment of climate change. According to the TAR-IPCC (2007), vulnerability in the context of climate change is "*the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes*". It has been summarised that vulnerability is a function of the character, magnitude, and rate to which a system is exposed to significant climate change and variation, its sensitivity, and its adaptive capacity. Here, there concepts were focused upon its three components viz. sensitivity, exposure and adaptive capacity. *Sensitivity* has been defined as 'the degree to which a system or species is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise)' according to the working group II of IPCC (2014). *Exposure* in context of climate change relates to the nature and extent to which a system is exposed to climatic variation (IPCC, 2001). It is also defined as the 'the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected' (IPCC, 2014). In the Fifth assessment report by the working group II of IPCC (2014), vulnerability is defined as "*the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt*".

The most commonly found distinct usage of the term vulnerability, is the concept of 'social vulnerability' and 'biophysical vulnerability'. The definitions of vulnerability in the climate-change related literature tend to be viewed in either of the two ways *i.e.*, either (i) in terms of the level of (potential) damage that a climate-related hazard can cause to a system (Jones and Boer, 2003), or (ii) as the existing condition of a system before it encounters a hazard event (Allen, 2003). The first approach is derived from the assessment of hazards and their impacts. Such climate-change-impact studies are known as first generation vulnerability assessments. The hazards and impact-based vulnerability studies view the vulnerability of a human system as the nature of the physical hazard(s), the likelihood or frequency of occurrence of the hazard(s), or the extent to which the system is exposed to hazard and the sensitivity of the system to hazards. According to Brooks (2003), the vulnerability as a function of hazard, exposure and sensitivity is said to be 'physical' or 'biophysical' vulnerability. Biophysical vulnerability deals with the ultimate effects or damage experienced by a system due to a hazard event. Jones and Boer (2003) measured vulnerability using indicators like monetary cost, human mortality, or ecosystem damage etc., thus meaning biophysical vulnerability. These indicators represent the outcome of a system rather than its state prior to the occurrence of a hazard.

Following this, Adger and Kelly (2000) defined vulnerability in terms of "ability or inability of individuals or social groups to cope with, recover from or adapt to any external stress on their livelihood or wellbeing". The term 'social vulnerability' was used to address the inherent vulnerability of human systems that arises out of its internal characteristics (Adger, 1999; Adger and Kelly, 1999). Research focused on social vulnerability leads to identification of most vulnerable groups or variations in vulnerability using which mapping can be done (Downing and Patwardhan, 2003). This is approach is precautionary in manner to climate-change problem as it is useful for drawing conclusions related to vulnerability to long term climate-change and thus identification of robust, policy recommendations (Kelly *et al.*, 1994; Kelly, 2000). Studies based on the social vulnerability definition analyse the processes that limit or favour the ability of system to respond to or cope with stress and means by which this ability can be offset or reinforced (Glantz, 1991). Outcome of the social vulnerability analysis forms a strong foundation for policy implications rather than less certain projection-based impact studies.

2.2 Paradigm shift in the concept of vulnerability assessment in different assessment reports of IPCC

IPCC is the leading organization conducting studies in climate change. The concepts and frameworks given by the Working Groups for different terminologies used in climate-change research are widely accepted in academic works. Due to progress in science, there is continuous emergence of newer concepts resulting in different dimensions and interpretations of the term 'vulnerability' and 'vulnerability assessment' were found in different dimensions of IPCC assessment reports which are as follows:

The Intergovernmental Panel on Climate Change (IPCC), in its Second Assessment Report, defines vulnerability as "the extent to which climate change may damage or harm a system." It adds that vulnerability "depends not only on a system's sensitivity, but also on its ability to adapt to new climatic conditions" (Watson *et al*., 1996).

Vulnerability was defined by the IPCC-Third Assessment Report (TAR) as "The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity." (IPCC, 2001). The term exposure is here defined as the nature and degree to which a system is exposed to significant climatic variations (IPCC, 2001). In this report sensitivity is defined as the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise) (IPCC, 2001). Adaptive capacity is defined as the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

The IPCC- Fourth Assessment Report (AR4) defines vulnerability in the same lines as the TAR *i.e*., Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity (IPCC, 2007). In this report the terms exposure, sensitivity and adaptive capacity are addressed to in the same way as in the TAR.

In the IPCC report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation, vulnerability has been defined as "the propensity or predisposition to be adversely affected" (IPCC, 2012). This concept has been expanded in the Fifth Assessment Report (Fig. 1). The definition of vulnerability as given by the IPCC- Fifth Assessment Report (AR5) differs in focus and breadth from the previous definitions in the Fourth Assessment Report and other IPCC reports as a result of progress in science.

It defines vulnerability as "the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt" (IPCC, 2014).

The above definitions show a clear shift in the conceptualisation of vulnerability over the years. With change in definitive framework, there has also been advances in vulnerability assessments. The definition of vulnerability in the TAR was challenged on accounts of inclusion of social vulnerability (O'Brien et al. 2004) and to reconcile with risk assessment (Downing and Patwardhan, 2005). It has been reported that the dynamic trait of vulnerability and its components is not adequately addressed in the Third and Fourth Assessment Reports of the IPCC (Rao et al. 2019). Recent literature on climate change suggests that the risks due to climate change result from the hazards arising out of climate change as well as the complex interactions among social and ecological systems rather than being externally generated alone. These aspects, the components of vulnerability and risk, interaction of these factors with the contextual factors are emphasised in the AR5. According to AR5, risk results from the interaction of vulnerability, exposure, and hazard.

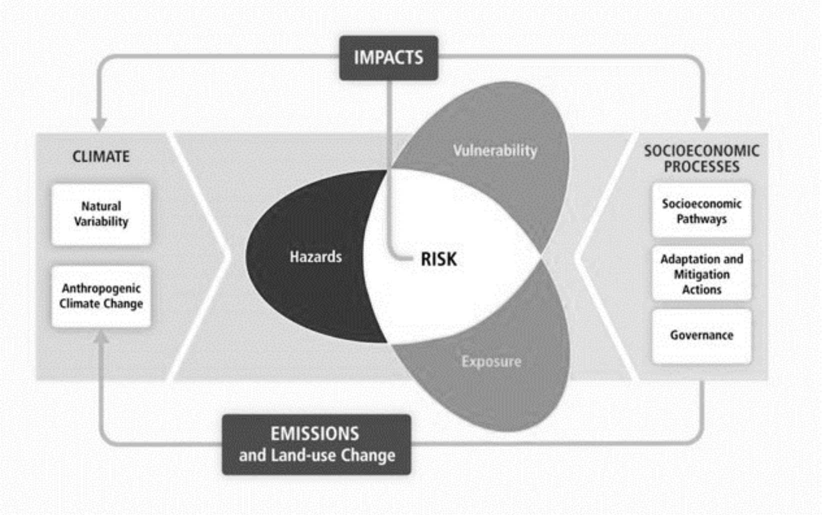

Figure 1. IPCC's AR 5 framework of risk assessment (Adapted from Oppenheimer et al. 2014)

The terms 'vulnerability' and 'exposure' are viewed differently in AR4 and AR5. Vulnerability was conceived as a function of exposure, sensitivity, and adaptive capacity in the Third (TAR) and Fourth Assessment Report (AR4) (Fig. 2a) but in the Fifth Assessment Report (AR5), 'exposure' has been disassociated from vulnerability (Fig. 2b). The reasons stated for this was that the previous conceptualization of vulnerability focused on the biophysical impacts of climate change while vulnerability is a 'social construct of risk', produced through social processes (IPCC 2012; Oppenheimer et al. 2014). According to the WGII-IPCC, vulnerability is an outcome of current or historical complex social processes and can be compounded by climate change-induced hazards and thus, can be sufficiently represented by 'sensitivity' and 'adaptive capacity'. In the TAR, exposure is defined as 'the nature and degree to which a system is exposed to significant climatic variations' (IPCC, 2001). Exposure was understood as stress, climate related shocks to which a system is exposed to that makes it vulnerable

(Sharma and Ravindranath, 2019; Rao et al. 2019). Whereas in AR5 exposure is relate to the individuals, systems, etc being exposed to the 'hazard' (Rao et al. 2019). As per the definition of exposure in AR5, it is a precondition to vulnerability (Oppenheimer *et al.*, 2014), which in turn is a predisposition to an external shock. Exposure is thus said to addresses the geographical location and their biophysical attributes, such as elevation (Jurgilevich et al. 2017).

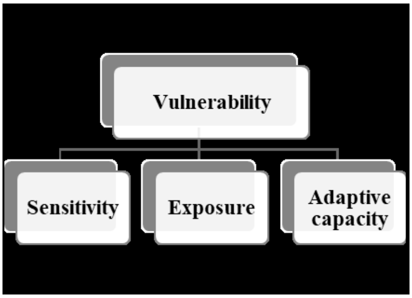

Figure 2a. Framework of vulnerability (IPCC, 2007)

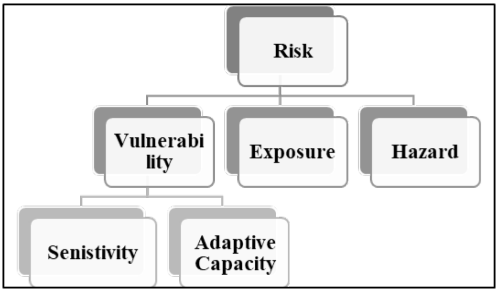

Figure 2b. Framework of vulnerability and risk (IPCC, 2014)

(Source: Rao et al. 2019)

Criticisms have risen regarding the use of the AR5 framework of vulnerability in vulnerability assessments. Three probable key reasons for this have been suggested by Ishtiaque et al. (2021) to be; (i) segregating 'exposure' may mask differential vulnerability led by differential exposure, (ii) path dependency of vulnerability assessments prevents innovation, (iii) lack of operationalization of the new framework.

3. Approaches of Vulnerability assessment

Vulnerability assessment has a long history. It is an ever-emerging area of research due to the rapid changes in environmental, economic and social systems. Vulnerability assessment is a key aspect of anchoring assessments of climate change impacts to present development planning. But due to its multidisciplinary nature of vulnerability, there is conflicting theory and terminology, incomparable studies. There are differing schools of thought such as the top-down approach, the bottom-up approach, the biophysical vulnerability, social vulnerability, integrated vulnerability assessment etc. Different methods of vulnerability assessment have been developed in different fields such as natural hazards, food security, poverty analysis, sustainable livelihoods and related fields. There is a need to integrate the diverging methods; upcoming research agendas have highlighted the need for development of comparative indicators of vulnerability in order to draw together emerging themes and enable more systematic assessment of the nature of vulnerability (Cutter, 2003, 2001; UNEP 2001; Clark et al. 2000). Assessing vulnerability is a very important aspect whenever we are trying to define the magnitude of any threat due to climatic changes (Kelly and Adger, 2000).

Due to the diversity in interpretations and concepts of vulnerability, variety of methodological approaches and tools have evolved that are being used to assess it. This is reflected in a vast variety of conducted vulnerability assessments with regard to the agricultural sector (Fellmann, 2012). Deressa et al. (2008) has discussed about two types of analytical methods used for measuring vulnerability *i.e*., (i) econometric approaches and (ii) indicator approaches. The econometric approach involves using house-hold based socio-economic data from survey which are then commonly assessed- vulnerability as expected poverty (VEP), vulnerability as low expected utility (VEU) or vulnerability as uninsured exposure to risk (VER). Different methods that have been identified being used for assessing vulnerability to climate change such as historical narratives, statistical methods, geographical information system and mapping techniques, comparative analysis, and agent-based modelling and indicator-based approach (Panda, 2016). Fellmann (2012) has stated that climate change vulnerability assessments can vary with respect to the methodological approach (*e.g*., experimental, modelling, meta-analysis, survey-based), the integration of natural and social science, policy focus, time horizon (short- to long-term), spatial scale (farm, local, national, regional, global level), consideration of uncertainties, and the degree of stakeholder involvement etc. Therefore, depending on the concept, interpretation and purpose of the study, the approaches and method of vulnerability is to be decided.

3.1 Index based approach of vulnerability assessment

Quantifying vulnerability using a set or composite proxy indicators is being widely used for vulnerability assessment in recent years (Fellmann, 2012). Climate-change literature shows that a number of studies has been conducted at different areas using composite index. In this method household level socio-economic data is used to assess vulnerability across different social groups (Deressa et al. 2008; Maiti et al. 2014, 2015a,b). Deressa et al. (2008) developed a vulnerability index in an integrated approach and based on that ranked the seven Ethiopian states. O'Brien and Leichenko (2000) and O'Brien et al. (2004) developed a vulnerability index to map hot-spot districts which were vulnerable to climate change in context of other stressors due to globalization. Maiti *et al.* (2014; 2015a,b; 2017) developed vulnerability index for the different agro-ecosystems of India.

In the indicator approach a wide range of indicators are developed and some of them are selected through expert judgment (Kaly and Pratt, 2000; Kaly et al. 1999), Principal Component Analysis (Easter 1999; Cutter et al. 2003), or correlation with past disaster events (Brooks et al., 2005). These can be used to link the biophysical and socio-economic characteristics of the system to the vulnerability through a quantitative function.

Some indicators, regarding the different components of vulnerability following a vulnerability framework, are identified from the whole set and then combined to indicate the levels of vulnerability (Deressa et al., 2008). The index so developed can be applied at local level, regional level, national or international level. In assessing vulnerability data can be collected at house-hold or community level and then based on these indicators the scoring and ranking of the surveyed house-holds or community can be done. A number of researchers like Adger and Kelly (1999), Kumar and Tholkappian (2005), Deressa et al. (2008), Moreno and Becken (2009), Nyong et al. (2008), Hahn et al. (2009), Ravindranath et al. (2011), Tambe et al. (2011) and Maiti et al. (2014; 2015a,b; 2017) have used index-based approach to analyse social vulnerability to climate change in their respective studies.

3.2 A Common Framework for Development of 'Social Vulnerability Index'

There are three major conceptual approaches for analyzing vulnerability to climate change: the socio-economic, the bio-physical (impact assessment), and the integrated assessment approaches (Deressa *et al.*, 2008). The integrated assessment approach combines both socio-economic and bio-physical approaches in order to determine vulnerability. The vulnerability mapping approach (O'Brien *et al.*, 2004; Kumar and Tholkappian, 2005) is a good example of this approach, in which both socio-economic and bio-physical factors are systematically combined to determine vulnerability. Thus, an indicator-based common framework to analyze social vulnerability is presented in Fig. 3 and discussed as below:

3.2.1 Selection of suitable indicators

Vulnerability analysis can be done based on the primary (for the household level) and secondary (for district level). Data will be mainly the climatic parameters (for exposure), crop and animal production and productivity (for sensitivity analysis) and socio-economic & available infrastructural facilities (for adaptive capacity). A number of indicators will be considered for district level and the household level vulnerability analysis. A tentative list of indicators of vulnerability analysis at the district and household level can be used from Maiti et al. (2014; 2015a,b; 2017) and Balaganesh et al. (2020). Principal Component Analysis will be applied to test the suitability of the each and every indicator to be considered in the vulnerability assessment as per the principle of Maiti et al. (2015a).

3.2.2 Calculation of weights of the indicators

Analytical Hierarchy Process (AHP), a psychology and mathematics based multi Criteria Decision Making approach conceptualized by Satty (2008), can be used to calculate weightage of the each of the indicators considered in the present study.

3.2.3 Calculation of Vulnerability Index Value

Selected indicators may be in different units and dimensions (for example, livestock ownership will be counted in number, whereas, availability of irrigation water will be quantified in percentage). Therefore, value of all the indicators must be transformed in normalized score (ranged between 0 and 1) before final analysis of the vulnerability index based on the following formula:

$$NV_i = \frac{X_i - X_{min}}{X_{max} - X_{min}} \text{ .... (I)}$$

$$NV_i = \frac{X_{max} - X_i}{X_{max} - X_{min}} \text{ .... (II)}$$

where, (i=1, 2, 3,……………n) indicators; NV_i = Normalized value of the i^{th} indicator; X_i=Actual value of the i^{th} indicator; X_{min} and X_{max} represents minimum and maximum value of the i^{th} indicator with in the entire data range, respectively.

Equation (I) is applicable for indicators having positive implications with vulnerability i.e. indicators of sensitivity and exposure and (II) is applicable for the indicators of adaptive capacity due to their negative implications with vulnerability.

Then, three separate indices will be developed for exposure, sensitivity and adaptive capacity. Finally, vulnerability of each household will be calculated as follows:

$$Vulnerability = Adaptive\ capacity - (Sensitivity + Exposure)$$

……………….. (III)

The overall vulnerability index facilitated inter-household/districts comparison. Higher value of vulnerability index indicated lower vulnerability. However negative value of the index indicated the net effect of adaptive capacity, sensitivity and exposure will be found to be negative. It may be considered as an alarming situation.

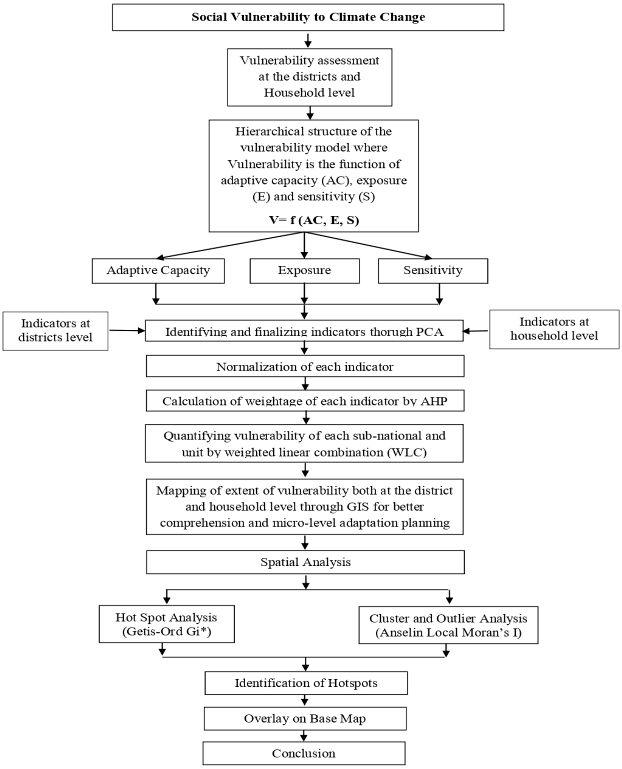

Figure 3. An inclusive framework to develop a social vulnerability to climate change index

3.2.4 Identification and mapping vulnerable hotspots

Spatial analytical tools like Global Moran's I and Getis-Ord Gi* will be applied to identify the vulnerable hotspots at the village level. The Global Moran's I will be calculated by using the following formula:

$$I = \frac{N \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} (x_i - \overline{x})}{\left(\sum_{i=1}^{n} \sum_{j-1}^{n} w_{ij}\right)\left(\sum_{i=1}^{n} (x_i - \overline{x})^2\right)}$$

Where,

N is the number of features (polygons) is mean of the variable

x_i is the value of attributes at a particular location

x_j is the value of attributes at a different location

w_{ij} is a weight indexing location of *i* relative to *j*

The Getis-Ord Gi* is calculated from the following formula:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{ij} x_j - \overline{X} \sum_{j=1}^{n} w_{ij}}{S \sqrt{\frac{\left[n \sum_{j=1}^{n} w_{ij}^2 - \left(\sum_{j=1}^{n} w_{ij}\right)^2\right]}{n-1}}}$$

Where,

x_j is the feature attribute value

j, w_{ij} is the weight of spatial relationship between feature *i* and *j*

n is the total number of features/polygons (blocks) and:

$$\overline{X} = \frac{\sum_{j=1}^{n} x_j}{n}$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j}{n} - \left(\overline{X}\right)^2}$$

4. Conclusion

The approaches available for vulnerability assessment are not ultimate. They are not definitive approaches; no such approach exists. They are merely an organization of available techniques into a convenient framework. The different concepts of vulnerability show that they are context and purpose specific.

Hence, as per the interpretations or the objectives of the study, policy questions to be answered, suitable definitions of the terms can be taken up. Accordingly, considering the availability of data and tools, the most suitable framework for assessment can be selected by the researcher following any of the available ones. But, suggested framework is more inclusive, hence, it may be used to analyze social vulnerability to climate change for the agrarian community in any agro-ecosystem of the country.

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Institutional Innovations in Climate Resilient Agriculture

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Abstract

Climate change is a global menace that has caused huge economic losses to the countries. It has brought widespread misery to the farmers. Climate-resilient agriculture (CRA) is an inclusive approach of sustainably using natural resources by means of eco-friendly and nature positive crop and livestock production systems in order to achieve higher productivity in the longer run. It stabilizes farm income even under consistent climate variability. Institutional innovations in this very direction are meant to promote climate resilient technologies and practices through collective action to build resilience among farming communities. The present chapter makes an attempt to briefly discuss the several institutional innovations brought about, upscaled and outscaled across the country to induce among the farmers proven research-based resilience mechanisms for sustaining farm productivity and profitability.

Keywords: Institutional innovation, climate resilient agriculture, climate change adaptation, mitigation strategy, climate smart village

1. Introduction

Climate change has proved to be a major threat for the farming communities across the globe, especially for the smaller and marginal ones. It has already caused huge economic losses for countries, especially in the climatically vulnerable areas and has brought widespread misery to a large section of the society. Climatic variabilities including abrupt temperature fluctuation and extreme climatic events have been reported to have reduced crop yield by 10-35% (Agarwal, 1990; Pathak et al. 2003; Swaminathan, 2009; Pathak et al. 2012). If the trend continues, it is estimated that the yield of two major staple food crops, rice and wheat will further go down by 8.1% and 6.51%, respectively by 2080 (Kumar and Sidana, 2019). The projected impacts are very likely to aggravate yield fluctuations in many other crops as well, thus impacting food security. It will leave immense challenges to Indian agriculture as a whole to feed 18% of the world population. The challenges will only multiply in the coming days as the frequency and duration of extreme climatic events like flood, drought, cyclone and heat wave will only increase. It will be difficult to recover agricultural productivity which has already been adversely affected (Pathak et al. 2015). In this very regard, technological innovations though are considered to pivot the combat of bringing resilience in agricultural practices; the same is only possible to be hastened through a structured institutional mechanism. Institutions lacking the mandate and knowledge of implementing climate-sensitive measures risk diminishing the adaptive capacity of the socio-ecological systems. Innovation of appropriate technologies, therefore, to a larger extent is dictated by the degree to which institutions are sensitive to respond progressively to climate change.

Institutional innovations are meant to promote collective action and build resilience among farming communities, in general and smaller farmers with limited resources, in particular. More than 85% of cultivable lands in the country are possessed by marginal and small farmers who constitute more than 80% of the total farming population of the country, and are hit hard by climate change impacts. Their poor resource base leaves them only with poor coping capacities to counter the detrimental effects of climate change. Capacity building of such farmers alongside other stakeholders by institutionalized participatory processes about location specific climate resilient agricultural technologies and practices will help them gaining access to vital knowledge. Such interventions will build in them confidence to cope with adverse climatic impacts. It is, therefore, imperative to build coping capacities of farmers through technological and institutional support to achieve the much desired resilience against climatic variability, and thus ensuring livelihood security of millions of resource poor farmers of the country.

2. Impact of Climate Change on Agriculture

Global climate changehas so far left enormous impact on agriculture both in direct and indirectforms, and will continue to do so. Apart from its direct effects on crop duration, photosynthesis, and evapo-transpiration, climatic variability in general and rise in atmospheric temperature in particular compared to the extant ambient temperature do have considerable indirect effects through land degradation, irregularities in monsoon, and irrigation water scarcity. The per capita water availability of the country has drastically gone down from 5177 cubic meter per year during 1950s to about 1820 cubic meter per year after 2000 (GOI, 2009). It is estimated that it will further go down, and during 2050s we will be left with only 1140 cubic meter water per person per year to endure our survival. The warming trend over the past 100 years in the country has indicated an increase of 0.6°C. Some of the most detrimental impacts of climate change have manifested in the forms of reduction in crop yield and it is projected that the same will continue to get affected (Table 1). Decline in soil fertility, loss of biodiversity, and abundance of pests, weeds, and diseases will be the other ill-effects to seriously ponder upon. The Inter-governmental Panel on Climate Change (IPCC) anticipated that the net result of climate change could be recurring drought and floods and significant changes inproduction environments; as a result of increase in atmospheric temperature, the estimated crop loss will be around 10-40% in India (IPCC, 2007). An estimated 1.5 per cent of GDP is lost every year due to the negative consequences of climate change.

Table 1. Projected changes in yields (%) of selected crops at maximum changes in temperature and rainfall

Crop	*Year 2035*	*Year 2065*	*Year 2100*
Pigeon pea	-10.1	-17.7	-23.3
Chick pea	-10.0	-18.6	-26.2
Wheat	-8.3	-15.4	-22.0
Rice	-7.1	-11.5	-15.4
Groundnut	-5.6	-8.6	-11.8
Sorghum	-3.3	-5.3	-7.1
Barley	-2.5	-4.7	-6.8
Maize	-1.2	-3.7	-4.2

Source: adapted from Birthal et al. (2014)

Note: Maximum change in temperature estimated as 1.3°C and rainfall as 7% by 2035, 2.5°C and 26% by 2065, and 3.5°C and 27% by 2100, respectively.

3. Climate-Resilient Agriculture

Climate-resilient agriculture (CRA) includes sustainable use of natural resources through eco-friendly and nature positive crop and livestock production systems to attain higher productivity in the long run and stabilize farm incomes even under consistent climate variability. CRA in its simplest sense encompasses improved access and utilisation of climate resilient agricultural technologies, increased adaptation of such crops and crop varieties and breeds of livestock which overcome climatic stresses, increased use of resource conservation technologies, and a transparent trade regime. It has the potential to alter a grim situation towards prosperity and sustain agricultural production to reduce hunger and poverty under climate change scenario. Planned adaptation is essential not only to enhance resilience of the agriculture sector to climate change, but also to make it sustainable. Several improved agricultural practices which evolved over time under different agro-ecological regions of India, have tremendous potential to serve as long term climate change adaption tools, if deployed scientifically.

Management practices which increase agricultural production under climatic variability tend to anchor climate change adaptation also since they increase resilience and curb yield fluctuations under climate change scenario. The most important measures of such sort will quintessentially include the following:

- Soil organic carbon build up
- *In-situ* soil moisture conservation
- Replacement of residue burning with residue incorporation
- Water saving, harvesting and recycling technologies for supplementing irrigation
- Adoption of drought and flood tolerant varieties based on agroecosystem
- Location specific agronomic practices and nutrient management, and
- Improved livestock feeds and feeding methods

4. Local Community and Institution: The Innovation Mechanism

Climate change impacts are reverberated mostly among the poor and marginalized sections of the societies. Population whose livelihoods are primarily natural resource based, are greatly affected by climate variabilities. Vulnerable areas, susceptible to long-term transformations of local socio-ecological systems, absorb majority of the shocks produced by climate change. Adoption of climate resilient technologies and practices is context specific and is often driven by the local priorities - of farmers, communities, and local governments (Rosenstock et al. 2015).

A growing emphasis is being observed on preparing for climate variations by encouraging community-led adaptation strategies, whereby local communities are enabled to improve upon their coping capacities in order to manage climate risks and fluctuations. Sustainable climate adaptation strategies draw alongside local practices and local knowledge the local power differences and divergent interests within the community. An awareness about the social actors, their diverse interests and purposes helps to set in the right context the notions of community participation in conscious climate change adaptation and mitigation efforts (Mukherjee et al. 2016). The importance of understanding local adaptation strategies as the result of multi-level discourses and interventions, and institutional practices involving a wide range of stakeholders, therefore, needs to be emphasized in climate change adaptation (Fig. 1).

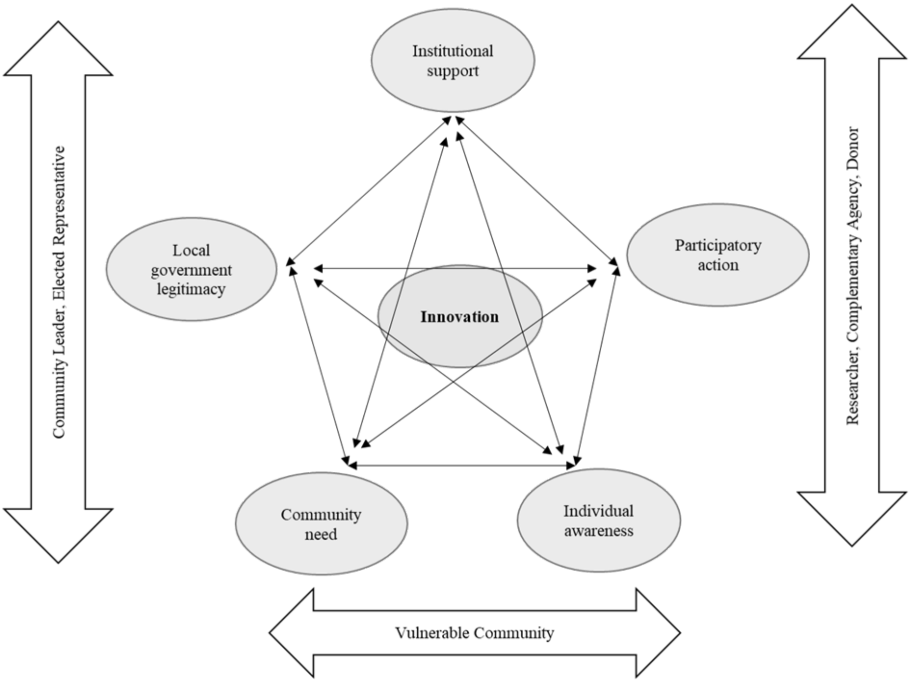

Figure 1. A conceptual layout of interactions, exchanges, and actors of institutional innovations

The term 'institution' connotes some sort of establishment of relative permanence distinctly connected with social processes (Hughes, 1936). North (1990) defined institutions as a set of formal and informal legal ground rules that establish the basis for production, exchange and distribution. In the specific context of climate change adaptation and climate resilient agriculture, institutions can be defined as social and scientific organizations established or repurposed for facilitating local innovations and enhancing the resilience of agricultural systems by deployment of improved coping mechanisms ensuring sustenance of the system against climate change impacts (Jasna et al. 2016). Institutions are expected to bring order in activities and interactions of the farming communities by structuring sustainable natural resource use behaviour, proactive roles, and synergistic relationships among the members. Therefore, they tend to be stable, inert, and resistant to change and innovation. Stability is in-fact the hallmark of institutions; it results from the repetitive social behaviour; underpinned by normative systems and cognitive understandings, fostering social exchange and enabling self-reproducing social order (Greenwood et al. 2008). And yet, in spite of all efforts to resist change, institutions do change, over time and circumstance, to varying degrees, and with varying degrees of disruption. Institutional innovations include both the creation of new institutions and change in existing institutions. The climate change action in India's context entails a noccurrence along a continuum that ranges from less disruptive or incremental innovation like, modification of an existing institution to more disruptive or radical innovation like, creation of a new institution. A striking example of such a classic innovation is 'micro-finance' which the financial institutions have brought-in to serve new or underserved populations with some different sorts of financial products and structures, commonly and more generally not offered. Institutional innovation is challenging and, therefore, often faces resistance, friction, and contestation because of the dynamic tension between institutional persistence and innovative change. As aptly stated by Hargadon and Douglas (2001) "*when innovations meet institutions, two social forces collide, one accounting for the stability of social systems and the other for change*."

5. Fostering Adaptation and Mitigation through Institutional Innovations

Institutional innovations in CRA either by strengthening the existing ones or initiating new ones have been successfully manifested in various forms –NICRA, custom hiring centre, village climate risk management committee, community seed bank, community fodder bank, commodity interest group, and (village managed) automatic weather station. Effective adoption of various interventions and promotion of community ownership are significant outcomes of institutional innovations in climate change mitigation strategies.

5.1 National Innovations in Climate Resilient Agriculture (NICRA)

The ICAR launched NICRA initially called National Initiative on Climate Resilient Agriculture (NICRA) in 2010-11 with a budgetary provision of Rs. 350 crores for the XIth Plan. Preparation of contingency plans for the rural districts of the country was the primary objective of the project. It led to selection of 100 most vulnerable districts to conduct demonstrations andapplication of climate resilient technological options and adaptation strategies.

5.2 Custom Hiring Centre (CHC)

CHC is an innovative institutional mechanism that facilitates resource poor farmers in timely access of required farm machineries, implements, and equipments for different farm operations. The main objective of CHC is to supply farm implements to resource poor small and marginal farmers at subsidized rates on hiring basis which enables them to take up farm operations on time. CHC emerged as a practical solution for the extant problems in rainfed areas which suffer from very short sowing window and poor accessibility of resource poor farmers to farm machinery resulting into miseries due to inability to sow the crop timely (Jasna et al. 2016). Following have been realized as specific advantages of CHCs:

- Provide small and marginal farmers regular and timely access to costly farm machineries aiding climate resilient agricultural operations.
- Reduce drudgery in climate change adaptation.
- Reduce cost of cultivation, indirectly helping the farmers to invest in CRA.

- Help in promoting crop diversification and in increasing cropping intensity.
- Bring efficiency in use of resources and inputs.
- Help in updating climate knowledge through farm advisories.

5.3 Village Climate Risk Management Committee (VCRMC)

VCRMC is another innovative institutional arrangement, aimed at collectively managing global risks of climate change impacts at the local level. The VCRMC finalizes climate resilient interventions byfarmers, target area selection, and coordinating with *gram panchayat* and elected (local) representatives.VCRMCs are formed with the approval of *gram sabha* in each village drawing representatives from all categories of farmers. A sub-committee within the VCRMC is entrusted with the responsibilities to run and manage the day-to-day affairs of the CHC. It maintains a bank account for all its financialtransactions relating to climate resilient agricultural interventions. The VCRMC additionally undertakes capacity building activities which have ensured post-NICRA sustainability of local climate actions.

5.4 Community Seed Bank (CSB)

Availability of quality seeds in right quantity has traditionally been the biggest problem faced by farmers. CSBs in this context are gradually emerging as effective rural institutions at the village level, enabling easy access of local farmersto diverse crop genetic resources and conserving agrobiodiversity of the farms. These institutions are serving asessential instruments in conserving local varieties and restoring almost extinct varieties. Seed banks ensure the adequate seed of the right varieties are available at right time and the price is by and large affordable. It enhances seed security. The idea of Community Seed Bank is quite simple, yet very powerful. Effective implementation of the same has the potential to solve a major part of the problems faced in carrying out farm operations. Climate resilient varieties are locally multiplied in the farms, processed, and then stored by the local communities to ensure easy access to improved seeds by more farmers. Community seed banks can assume multiple forms; stored in pots in a shed or community buildings, stored in clay pots on the floor or in a family granary. Serving as an immediate backup to the informal seed sector, CSBs help in keeping the farming community motivated to contribute in sustaining the institution and ensuring seed security in the face of climate change.

5.5 Community Fodder Bank (CFB)

Adequate availability of feed and fodder is a critical issue in livestock farming especially under the influences of climate variability. Poor feeding resources lead to poor animal health, lesser productivity, and thereby sub-optimal performance of the livestock sector in the country. Presently, the country endures a net deficit of 63% in green fodder, 24% in dry crop residues, and 64% in feeds. Dry seasons generally witness great shortfalls both in quantity and quality of forage, and under the influence of a changing climate the situation has further worsened. A practical alternative to counter the effect is establishing community fodder banks. Though they do not fulfil 100% of feed requirements, they ofcourse are great alternatives to supplement dry season forage availability. Besides, the approach aids in reducing fodder collection based drudgery of rural women who need to spend an average of 1.38 weekly hours in fodder collection activities.

5.6 Commodity Interest Group (CIG)

Farmers' organization is a very useful mechanism for mobilizing even the most laggards towards collective action and self-help. The aim of such organization is improvement of socioeconomic conditions of farmers and the farming communities as a whole. Commodity Interest Group (CIG) is an independent group of farmers whose interests are built around a specific commodity with a shared goal. These groups are self managed with minimum external support. The members of a CIG pool their resources in order to generate more resources. In the face of climate change, CIG serves as an excellent risk sharing institutional mechanism that many state governments have been increasingly adopting and promoting.

5.7 (Village level) Automatic Weather Station (AWS)

Timely information about weather and climatic conditions is of paramount importance in the entire crop cycle –from selection of the most suitable crop/ variety up to postharvest operations and marketing. Real-time access to such information on regular basis enables farmers to manage various risks and uncertainties associated with crop production. The accomplishment is subjected to setting up of a vast network of weather observatories equipped with rapid communication facilities. A network of automatic weather stations (AWS) perhaps is the most feasible means of recording and obtaining real-time weather data; it helps in location-specific forecasts, aiding farm management decisions. Additionally, agrometeorological advisories help to stabilize crop yield through efficient management of agro-climatic resources and critical inputs. AWS can be seen established in majority of the KVK experimental farms of the country. Likewise, mini weather observatories have become an integral part of village level real time weather monitoring in large number of villages, adopted under NICRA. Information on rainfall, temperature, sunshine hours, and wind speed are stored, archived, and shared.

6. Climate Resilient Village: Integration of Institutional Innovations

Integration of institutional innovations envisages testing and validation of a portfolio of climate resilient interventions that helps the farm households to make progressive changes in selection of crops, cropping patterns, and livestock systems in a robust manner towards a resilient production system. It can be done in different scales. A village being consisting of contiguous farms, well integrated in a landscape and also being a local administrative unit within which the communities own the land and can take decisive actions, the integration best takes place in form of a Climate Resilient Village (CRV).

The concept of CRV is inspired with effective implementation of climate resilient measures at a scale to cover an entire village in saturation mode (Fig. 2). It necessarily depends upon the resource endowments of inhabiting farmers. The basic idea is to undertake a single or a bucket of interventions for imparting resilience to the production systems. The CRVs adopt a portfolio of interventions covering the full spectrum of farm activities comprising adaptation, mitigation, natural resource management, scientific crop management, and livestock production. However, the concept of CRV must not be limited only with demonstration of CRA technologies; it should rather be seen in the broader perspective of institutionalizing mechanisms at the village level for continued adoption of CRA practices in a sustainable manner. The strength of the approach lies in inclusiveness of its actors - farmers, village communities, researchers from different disciplines, NGOs, and other stakeholders, all coming together to test a range of options in an integrated way.

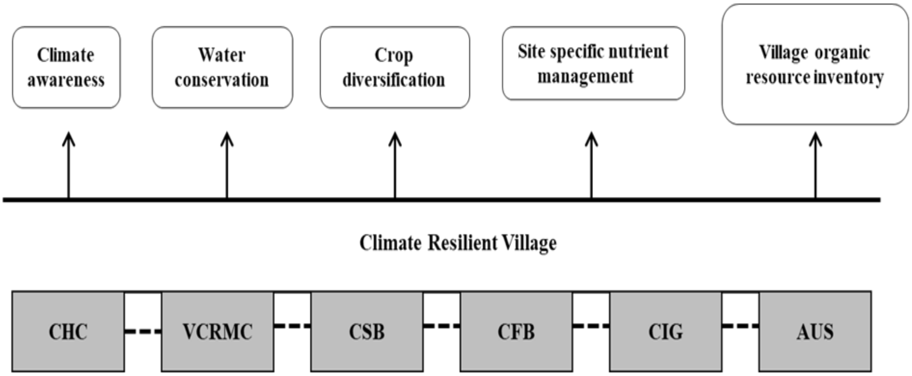

Figure 2. A conceptual layout of Climate Resilient Village

7. Conclusion

Technologies developed by the National Agricultural Research and Education System (NARES) of the country are tested, refined, and applied through different outreach programs and recommended for various agro-climatic conditions of the country. The technologies can effectively address climate change and food security concerns. They are mostly tailor-made to meet the objective of enhancing agricultural productivity. They increase resilience of farming systems against climate change, and contribute to mitigation of climate change impacts, and therefore can contribute to CRA when implemented in synergetic manner. Replication of a well functioning institutional arrangement enhances outstretch of the benefits of climate resilient technologies at newer regions. The critical role institutions in implementation and execution of interventions pertaining to dissemination of climate resilient technologies must be unveiled for establishing their effectiveness and thereby extending the success in achieving the goals of CRA.

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Chapter 25

Farmer-centric Central Government Schemes and Programmes for Making Agriculture Climate Resilient

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Abstract

Climate change has affected the goal of poverty alleviation in the country in many ways. The adaptation and mitigation strategies against climate change, adopted so far in the country have taken various forms; grounded both in formalized institutional innovations, informal local wisdoms, and community level collective actions. Government initiatives in this very regard are of paramount importance especially in the context of increasing extreme climatic events. Government interventions to mitigate climate change impacts mostly are manifested in forms of insurance schemes, direct benefit transfer programmes, infrastructure development projects, R&D in mission mode, and financial products. The present chapter discusses the various farmer-centric central government schemes and programmes implemented by the present Union Government to build adaptive capacity among farmers for making agriculture climate resilient.

Keywords: Climate resilient agriculture, central government climate action, crop insurance, climate service, model village

1. Introduction

Impending threats of the ever changing climate are looming around every nukes and corner of the globe. Climate change largely impacts the food production systems, food security, livelihoods, and assets, thereby leaving enormous impact on the overall economies of the nations. It presumably causes 1.5% loss in Gross Domestic Product (GDP) of India every year. Reports suggest that the country may incur an annual loss of 3-10% of GDP by 2100, and poverty may go up by 3.5% in 2040 due to climate change (Picciariello et al. 2021). Climate change has drastically slowed down the pace of poverty alleviation in India. It has immensely contributed in escalation of the level of inequality. The fastest warming districts have witnessed an estimated 56% lesser growth in GDP compared to the slowest warming districts (Burke and Tanutama, 2019). The Economic Survey 2017–18, GoI predicted a decline in farm income by as much as 25% in some pockets of the country due to the deleterious effects of climate change (Sarkar, 2018). Extreme climatic events- heavy rainfall and severe floods, heatwaves, and catastrophic storms have been reported to have increased in frequency to leave detrimental effects on lives and livelihoods of people.

The risks associated with climate change can be effectively addressed by enhancing adaptive capacity and building resilience. Farmers, the most vulnerable population to climatic variabilities, largely depend upon resilience of both social and ecological systems for an economically rewarding and stable livelihood. Resilience is the ability of a system to bounce back by essentially engaging judicious outlay of natural resources (land, water, soil) and genetic resources through adoption of best practices (Rao et al. 2016). The concept of climate resilient agriculture is central to a comprehensive knowledge about the vulnerability of the sector to the potential impacts of climate change. Resilience of social systems pertains to households, communities, and regions; extent of resilience however depends upon resources and knowledge that the farming community can mobilize in relation to the services provided by different institutions and governments. Agriculture being a source of livelihood for billions—particularly of those sustaining with meagre amount of resources—their wellbeing directly contributes to society's resilience. Climate resilient agriculture (CRA) comprises adaptation strategies and resilient practices which increase coping capacity of farmers to readily respond to climate-related disturbances and shocks.

Government initiatives to make agriculture climate resilient is of paramount importance especially in developing countries like India. Per capita spending by the government in its combat with climate change counts a lot, especially in the context of rising frequency of the extreme climatic events. The Finance Minister Smt. Nirmala Sitharaman, in her latest Budget speech delivered on 1st of February, 2022, attached remarkable emphasis on building resilience in agriculture against the vagaries of climate. As announced, the government is on its way to launch Sovereign Green Bonds for backing eco-friendly infrastructure. As Green Bonds are debt instruments, proceedings from these may be well utilized by the government to fund projects having positive impact on environment, and thus will reduce carbon dependency. At the recently concluded United Nation's Climate change conference, 'Conference of Parties (COP 26)' held at Glasgow, UK, the Government had made a commitment to achieve the target of zero-carbon emission by 2070. An additional allocation of Rs. 19,500 crores for production-linked incentives (PLI) for manufacturing of high-efficiency solar modules has also been made in the present budget. The proposal to co-fire 5-7% biomass pellets in thermal power plants resulting in an estimated reduction of 38 million tonnes of carbon dioxide (CO2) annually, should ideally provide an income to the farmers and reduce stubble burning. Special focus has further been laid on private forestry, agroforestry, and on supporting SC/ ST farmers taking up agroforestry. The Government will promote the provisions of blended finance with 20% government's share for climate action, and clean technology.

2. Climate change, impact, and resilience

Climatic variability especially monsoon significantly impacts the Indian economy; the GDP drops by 2–5% in drought years (Gadgil and Gadgil, 2006). As evident, extreme rainfall and temperature events are increasing, and very likely to further rise in the future. A specific extreme event can hardly be attributed to climate change but recent studies have highlighted that the June 2013 flooding in North India is very likely to be a consequence of climate change which resulted in an abrupt increase in rainfall by 60–90% (Cho et al. 2016; Singh et al. 2014). The 2005 Mumbai flood affected an estimated 20 million people. The 2008 Bihar flood drove huge number of masses to shelter houses. The state of Kerala witnessed the worst ever flood in 2018 due to an unusually high downpour. The Economic Survey – 2018 of the Govt. of India attributed US$ 10 billion annual loss to climate change. The arid and semi-arid regions of the country face severe drought; farmers miserably suffering from abrupt changes in the rate of precipitation. The Western part of Rajasthan, several pockets of Haryana, Uttar Pradesh, and Maharashtra, the Southern parts of Bihar and Gujarat, the entire states of Madhya Pradesh and Karnataka, and Northern Andhra Pradesh have been identified as highly vulnerable to drought (Bhadwal et al. 2007).

Since the negative impacts of climate change have intensified over time, it has become quite essential to build resilience of the farming community by means of amalgamation of coping mechanisms in a synergistic way. Resilience is thought to be achieved when a farm unit is not affected by climatic variability in production of a particular commodity. Resilience seeks to regulate the capacity of a system to absorb and recover from perturbations or disturbances in a timely and efficient manner, while ensuring the preservation, restoration, or improvement of its structures and functions (IPCC 2012). Climate Resilient Agriculture (CRA) comprises adaptation and mitigation strategies in agriculture to increase capacity of an entire agricultural production system to efficiently respond to inconsistent climatic events and disturbances. CRA is a means of resisting damage and achieving quick recovery in agricultural production. Under the conditions of unavoidable damage caused by severe floods, prolonged drought, cyclone etc., CRA provides the production system enhanced ability to bounce back. CRA thus is characterized by early recognition of threats to be responded to, by essentially involving judicious outlay of natural and genetic resources in combination of adoption of best practices. The National Academy of Agricultural Sciences (2013) suggested the following policy measures for integrating climate resilient agriculture in planning:

1. Increasing concessional credit for small and marginal farmers who adopt climate resilient agricultural practices; incentivising farmers who adopt CRA.
2. Laying emphasis on community organizations and farmers' groups in satisfying the critical needs of farmers by means of custom hiring, resource mobilization, natural resource management, and collective marketing.
3. Empowering the *Gram Panchayats* to assume the nodal position in climate-resilient programme implementation and disbursement.
4. Evolving a national policy on disaster management in agriculture for more efficiently tackling major climatic events like cyclones and floods devastating the agriculture and allied sectors.
5. Implementation of NCF (National Commission on Farmers) recommendations pertaining to the establishment of a National Agricultural Risk Management Fund for need-based and timely distribution.
6. Documentation of success stories pertaining to climate change management; conduct of pilot demonstrations, and establishment of climate smart villages throughout the country.
7. Introduction of large scale soil and water conservation measures; revitalization and management of common property resources.
8. Building priority infrastructure- markets, information gateways; creating opportunities in non-farm sector especially in vulnerable regions to enable farmers in diversifying incomes.

3. Central Government Climate Action Initiatives for Mainstreaming CRA

Climate change adaptation and mitigation takes various forms; grounded both in formalized institutional innovations and informal local wisdoms (Mukherjee et al. 2016). Government initiatives in mitigating climate change impacts mostly can be seen through various insurance schemes, direct benefit transfer programmes, infrastructure development projects, R&D in mission mode, and financial products. Agricultural insurance is an excellent means of stabilizing farmers' income and enhancing their capacity to invest by guarding their livelihoods against the disastrous effects of losses due to natural hazards and price fluctuations in the market. It cushions the shock of financial losses by spreading the losses over space and time, therefore, has been extensively tried out in making farm based livelihoods climate resilient. Infrastructure development in climatically vulnerable areas has often been seen as the most productive strategy to bring resilience. Water harvesting structures in drought-prone areas and hill ecology, water conservation technologies in agriculture through micro irrigation have also proved quite effective in the fight against climate change. Similarly, national governments of the countries spend in R&D and/or roll out projects in mission mode to reach a specific target. The National Innovations on Climate Resilient Agriculture (NICRA) of India is one such classic example. The present article however limits its focus only to the central sector schemes benefitting farmers directly by holding their hands in the fight of climate resilience.

3.1. National Crop Insurance Programme (NCIP)

The central government sponsored National Crop Insurance Programme (NCIP), formulated by merging National Agricultural Insurance Scheme (NAIS), Modified National Agricultural Insurance Scheme (MNAIS), Weather Based Crop Insurance Scheme (WBCIS), and Coconut Palm Insurance Scheme (CPIS) came into force during *Rabi*, 2013-14. The programme covers all the districts of the country. States which initially failed to implement the scheme at villages / *gram panchayat* level were permitted to implement at higher unit area level (i.e., upto a cluster of maximum 15 villages) with prior approval of DAC for 3-5 years. In order to compensate losses in horticultural crops due to the perils of hailstorm, cloudburst etc. a provision was made for add-on/index plus products. This is in fact a major feature of WBCIS component of the programme. Loanee farmers are compulsorily covered under the programme whereas non-loanee farmers are free to choose among the MNAIS and WBCIS components. NCIP adopts a mechanism by which cost of losses of few can be distributed among many insured, and therefore, cannot prevent economic losses completely.However, it provides the farmers the confidence of recovering at least a minimum amount of loss under unforeseen predicaments, and thus forms an important component in the safety-net programmes of the country.

3.2 Pradhan Mantri Fasal Bima Yojana (PMFBY)

The PMFBY scheme was launched in India by the Ministry of Agriculture & Farmers Welfare, Govt. of India during Kharif 2016 for rendering financial assistance to farmers suffering crop losses/ damage due to unforeseen events. It thus aims at stabilizing farmers' incomes to incentivize them not to leave farming under shock and distress. The scheme further envisages building confidence in farmers to adopt innovations and modernize farm operations. Besides providing farmers risk coverage, the growth oriented vision underlying the scheme ensurescredit flow in agriculture sector, promotes crop diversification, and makes the sector competitive even under unconducive circumstances.

A multi-agency framework is central to effective implementation of the scheme. It involves selected insurance companies, financial institutions, and state government departments. The entire scheme operates under the aegis of Department of Agriculture, Cooperation & Farmers Welfare (DAC&FW), Ministry of Agriculture & Farmers Welfare (MoA&FW), Government of India (GOI). Selection of insurance companies from the list of empanelled insurance companies to act as implementing agencies is done by the state governments.The scheme covers both loanee and non-loanee farmers as well as sharecroppers and tenant farmers. However, it is compulsory for loanee farmers. Crops for which insurance is offered are notified by respective state governments in *Rabi* and *Kharif* seasons.

Area approach is followed in PMFBY in which village/*gram panchayat* or equivalent unit is considered as insurance unit (IU) for major crops as notified by state government. For other crops the IU can be block or even district. Risks covered in course of the scheme are: prevented sowing/planting, losses to standing crop (sowing to harvesting) due to non-preventable risks, post-harvest losses (up to a period of 14 days), and localized calamities such as hailstorms, landslides or inundation. However, losses incurred on account of malicious damage, theft, act of enmity, grazing, damage by domestic/ wild animals, and postharvest losses due to bundling and heaping of harvested crop at a place before threshing, and other preventable risks, are excluded from insurance coverage under the scheme.

PMFBY fixes a uniform premium of 2% of sum insured or actuarial rate whichever is lesser for *Kharif* crops, 1.5% or actuarial rate whichever is lesser for *Rabi* crops, and 5% or actuarial rate whichever is lesser for commercial and horticultural crops. The balance premium is paid equally by the state and central government. No upper limit is fixed on government subsidy for actuarial premium rate. PMFBY has three levels of indemnity: 70%, 80%, and 90% corresponding to three categories of areas classified based on risk - high, moderate and low, implying that the farmers themselves have to bear 30%, 20%, and 10% of the losses respectively. The levels are applicable to all notified crops by respective state governments. There is no discrimination among loanee and non-loanee farmers in terms of sum insured (SI) per hectare. The SI is equal to the scale of finance (i.e., cost of cultivation plus some profit) as decided by the District Level Technical Committee (DLTC), and declared in advance by the State Level Coordination Committee on Crop Insurance (SLCCCI). Final claims are paid to farmers electronically within three weeks from receipt of crop yield data by the insurance company. A crop insurance portal (www.agri-insurance.gov.in) has been created under PMFBY for better administration, coordination amongst stakeholders, proper information dissemination, and transparency.

3.3 Pradhan Mantri Krishi Sinchai Yojana (PMKSY)

Cultivation in unirrigated areas owing to its substantial dependency upon rainfall manifests itself into a high risk – low profit venture. Assured or protective irrigation brings resilience against rainfall uncertainty, and thereby boosts confidence in farmers to move on with the scale of farming. The *Pradhan Mantri Krishi Sinchai Yojana (PMKSY)* in this very regard is a farmer-centric scheme which was brought into effect during 2015-16 with a financial allocation of Rs. 50,000 crore spreading over 2015-2020 period with an additional outlay of Rs. 20,000 Crore placed at the disposal of NABARD. It envisages expansion of cultivable area under assured irrigation by convergence of investments in irrigation at the field level. The scheme aims at improving water use efficiency by enhancing adoption of precision water use and water saving technologies and reducing water wastage at the farm. Enhancing recharge potential of aquifers has been laid additional emphasis under the scheme. Exploring the possibilities of recycling treated municipal waste water for the purpose of peri-urban agriculture and sustainable water conservation has been a special feature of the scheme. The scheme further targets attracting greater private investment in precision irrigation system.

PMKSY had been conceived amalgamating the then ongoing threeimportant irrigation schemes namely –

i. Accelerated Irrigation Benefit Programme (AIBP) of the Ministry of Water Resources, River Development & Ganga Rejuvenation
ii. On Farm Water Management (OFWM) programme of the Department of Agriculture and Cooperation (DAC)
iii. Integrated Watershed Management Programme (IWMP) of the Department of Land Resources.

Presently, the scheme has the following four components:

1. AIBP (Rs.11,060 crore)
2. *Har Khetko Pani* (Rs. 9,050 crore)– to construct one water harvesting structure in each village.
3. Per Drop More Crop (Rs.16,300 crore) – to increasingly support micro irrigation.
4. Watershed Development (Rs.13,590 crore)

PMKSY adopts a dynamic annual fund allocation methodology instead of incremental budgeting. It mandates states for allocation of more funds to the irrigation sector to become eligible for PMKSY funds. About half of the fund is allocated to projects in districts having –

(i) larger share of unirrigated areas
(ii) lesser agriculture productivity compared to state average
(iii) higher proportion of small and marginal farmers and SC/ST population

The remaining (50%) of the fund is prioritized for operationalising /saturating projects in terminal stage of completion.

3.4 Gramin Krishi Mausam Sewa (GKMS)

The meteorological services have significant impact on the society as a whole in the face of climate change. Over the years, specialized services tailor-made for state-of-the-art monitoring, detection and early warning of extreme weather phenomena including heavy rains, severe thunderstorms, dust storms, tropical cyclones, cold and heat waves, and snowfall are helping the farmers to find out suitable adaptation and mitigation strategies. Besides agriculture sector, the Indian Meteorological Department, Pune since long has been rendering its services to other climate sensitive sectors as well, such as irrigation, shipping, aviation, offshore oil explorations etc.

Gramin Krishi Mausam Sewa (GKMS) was started in 2015 to render crop specific advisories to farmers twice a week at district level by the IMD in collaboration with the Indian Council of Agricultural Research and State Agricultural Universities.

It aims at developing an advanced weather prediction system for block level forecasts, precisely applicable for next 3-5 days and thus providing advisories to the farmers for making agriculture climate resilient. The same has been envisaged to be achievable through setting up of District Agro-Met Units (DAMUs) in all the districts of the country for extending Agromet Advisory Services (AAS). The scheme specially focuses upon expanding outreach of weather based AAS to the farmers through multiple communication means, feedback collection and impact assessment of AAS. Advisories are broadcasted through multimedia channels and also through SMSs to help farmers plan farm operations according to the weather.

GKMS is one of the major components of the IMD scheme 'Weather & Climate Services.' The other components of the scheme are - Climate Services, Augmentation of Aviation Meteorological Services, Capacity Building, and Training in Operational Meteorology. The scheme itself is a part of the umbrella scheme entitled 'Atmosphere and Climate Research Modelling - Observing Systems & Services (ACROSS)' of the Ministry of Earth Sciences, GoI. It aims at providing efficient weather and climate services across the country in various sectors.

3.5 Mausam – A Climate Service Mobile Application

Climate change has significant impact upon the conditions affecting agriculture; more severe warming, frequent floods, and severe droughts have been reported to have drastically reduced yield of crops. Early warning and forecasts are therefore considered foremost important to save produces by planning operations in climate-appropriate manner.

In this specific direction, the mobile application, namely *Mausam* was launched with the purpose of –

(i) providing city-wise weather forecasts

(ii) providing nowcast services (three hourly warning)

(iii) other important early warnings

Mausam has been designed and developed jointly by the IMD, Pune; Indian Institute of Tropical Meteorology (IITM), Pune; and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad. It has been made available both on Google's Play Store and Apple's App Store. Among the services offered by *Mausam* are: current weather information including temperature, wind speed, humidity, and wind direction. The information is updated eight times a day. In case of severe weather, the probable impacts are also included in the warning. Weather information of the past 24 hours is also made available on the app. It also issues colour coded alerts - red, yellow, and orange. The app makes early warning ahead of dangerous weather for all the districts of the country twice a day for up to five days. The app has immense potential to make agriculture climate resilient through timely information and weather alert.

3.6 Pradhan Mantri Kisan Samman Nidhi (PM-Kisan)

PM-Kisan is a 100% central government funded farmer centric scheme aiding small and marginal farmers of the country to bring resilience against climate change in farming. The scheme exactly did not start with the sole purpose of bringing climate resilience in farming though. Rather it became operational in 2018 as an income support scheme in the mode of direct benefit transfer, aimed at supplementing farmers' financial needs to secure crop health, yield, and income. The scheme functions under the Ministry of Agriculture and Farmer's Welfare (MoAFW), GoI. In 2020-21 (FY), Rs. 75,000 Cr. were allocated to the scheme, accounting for 53% of the Ministry's budget though in the revised estimate it was brought down to Rs. 65,000 Cr. The beneficiaries of the scheme receive Rs. 6,000/- per year in three equal instalments. Initially, the cash transfer was meant only for small and marginal farm families for every four-month period. Later on June 1, 2019, following a Union Cabinet decision, the scheme benefits were extended to all categories of farmers irrespective of land size. A direct transfer of funds to the beneficiaries' bank accounts makes the scheme highly transparent and effective. Therefore, the banking infrastructure created through *Pradhan Mantri Jan Dhan Yojana* (PM-JDY) and compulsory Aadhar enrollment play key roles in extending benefits of the scheme to the right individuals.

Since PM-Kisan is a central government scheme, the entire financial accountability lies with the Government of India. The major responsibilities of state and UTs include beneficiary identification, database creation and management, and integration of the banking infrastructure with GOI's Public Financial Management System (PFMS). Beneficiaries of the scheme are identified by the states based on their land records. As there are no specific criteria for usage of the PM-Kisan fund which means the farmers are free to spend their cash transfer anywhere they like, it has immense potential to bring resilience in farming in the face of climate change (Ghosh et al. 2022). Farmers, especially the small and marginal ones who lack access to institutional credit, sustaining on the mercy of village money lenders suffer from poor risk taking ability. Cash transfer in this context helps such farmers to gain some amount of liquidity, adding to their potential of practicing climate resilient agriculture. It becomes more important in the climatically vulnerable pockets of the country. The scheme should find a way to include landless agricultural laborers and tenant farmers who at present do not receive the income support.

3.7 Saansad Adarsh Gram Yojana (SAGY)

The *Saansad Adarsh Gram Yojana* (SAGY) was launched by the present Union Government in 2014 with the goal of developing three numbers of model villages (*Adarsh Grams*) by the year 2019. The primary target of development of at least one such village was to be accomplished by 2016. Five such model villages will be selected and developed by 2024 taking one per year. The scheme is a classic example of aligning infrastructure development with the Gandhian philosophy by having equal focus on the values of national pride, patriotism, self-confidence, community spirit, and infrastructure development (Bhattacharyya et al. 2021). The scheme envisages integrated development of a village in multiple directions which cover agriculture, health, education, sanitation, environment, livelihoods etc. To reach the goal a Village Development Plan (VDP) is prepared for every identified *Gram Panchayat*. A special focus is laid on the most vulnerable households. Till date, a total number of 2579 *Gram Panchayats* have been identified under SAGY; 1957 Gram Panchayats have prepared VDPs and uploaded on the SAGY portal (GOI, 2022). SAGY is expected to take on priority climate resilient farming system development in the targeted villages.

3.8 Soil Health Card Scheme

The Scheme was launched in February, 2015 by the present Union Government with the objective of empowering farmers with the much required knowledge about soil conditions of their respective farms for enabling them to seek appropriate assistance of agricultural experts in soil amendment and land amelioration, and thereby taking suitable farming related decisions for sustainable agriculture. The farmers are issued with soil health cards (SHCs) containing detailed information on test based soil nutrient status of the farmland. The card further specifies recommended fertilizer dose for improving crop productivity through judicious input use. The total target fixed under the scheme was 10.48 crores of SHCs since its inception.

4. Conclusion

Substantial literature explores the probable impact of climate change in India, and institutional and grassroots strategies tried and adopted in wider scales. However, from policy perspective, detailed analysis of the pledges at global platforms being internalized into government schemes and programmes, and the impact thereof, are yet to be done. Policy instruments like agricultural insurance, cash transfer, and direct benefit transfer are quite efficient and dependable means of protecting farmers from financial losses. Sudden financial requirements arising out of uncertainties in the face of climate change and other unforeseen shocks can be taken care of to some extent by such instruments. Government policies, programmes, and schemes play a crucial role in ensuring access to these especially in the under-developed and developing countries with meagre adaptive capacity at the individual levels of resource poor farmers. The Union Governments in India since long have tried to popularize agricultural insurance though the same has not been able to make much headway in the country. The other instruments, e.g., mobile app based agro advisory, cash transfer and direct benefit transfer are comparatively new in the country. Climate-responsive programmes and components are going to grab the focus in monetary outlay in the coming years.

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Chapter 26

Information and Communication Technologies (ICTs) interventions for Climate Resilient Agriculture

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Abstract

The agricultural production system must adapt over time to meet the ever-increasing demand for agricultural products. In order to make vital judgments in everyday agriculture information available to the farming community, accurate and speedy actions are required. Accurate weather forecasts throughout all temporal ranges are desirable for optimal agricultural intervention planning and management. Climate risk management is crucial for small and marginal farmers to sustain their livelihoods. Decisions based on scientific information and understanding can be made with the help of an ICT-based system. The internet, telecommunications, satellite technology, and geographic information systems are all examples of technological advancements in the information and communication fields that have altered daily life. In order to achieve sustainable growth in all parts of the agriculture industry, now is the best time to integrate and use agrometeorological data via ICT systems for climate resilient farming. ICTs can serve as strategic enablers of action within these communities to raise knowledge about, reduce, monitor, and adapt to climate change. Despite their diversity, rural agricultural contexts share fundamental traits and constraints (geographical, economic, and social) that are aggravated by climate change impacts and need the use of new techniques based on emerging and conventional knowledge and information resources.

Keywords: Climate change impact, climate risk management, ICT-based system, climate resilient farming

1. Introduction

The agriculture sector is the most vulnerable to climate change, and climatic stress such as drought, landslides, soil erosion, floods, and hailstones, cyclones etc. reduce agricultural productivity as well as livelihood security in rural India. A resilient farm has more capacity to lessen physical and financial damage than comparable farms and ranches utilizing traditional management approaches when faced with shifting weather patterns or an extreme weather event and it can recover from harm more quickly. A resilient farm is also more adaptable to future problems and possibilities brought on by changing climate circumstances. According to the UN Food and Agriculture Organization (FAO), feeding the world's population will necessitate a 60% increase in total agricultural production. The food security issues are enormous, as many of the resources required for long-term food security are already stressed. Climate change, on the other hand, is already having a negative impact on agricultural production both globally and locally. Crops, livestocks, and fisheries are all predicted to be more vulnerable to climate change in the next decades, particularly in low-income nations with little adaptation potential. Agriculture's impact jeopardises both food security and agriculture's vital role in rural livelihoods and development. Hence the risk assessment and local community adaptation plans for the agriculture sectors are being produced as a result of increased knowledge of climate change adaptation through various programmes. Climate Smart Agriculture (CSA) and Adaptive Agriculture (AA) are two recent initiatives that have been launched by the Government to make agriculture climate resilient. The new method of farmer education based on information and communication technologies has shown them a new way to fight for agriculture sector to make this important primary sector of the country climate resilient. Information and communication technologies (ICTs) are gaining popularity, especially in agriculture and allied sectors.

2. Role of ICT in Agriculture

Information and communication technology can be utilized in rural areas to offer new activities, services, and applications, as well as improve current ones. ICTs have the potential to play a critical role in combating rural poverty and enabling sustainable development by creating information-rich communities and supporting livelihoods. By using ICT, large amounts of data and information can be efficiently generated, preserved, analyzed, communicated, and used to improve agriculture. It has the potential to boost productivity by providing farmers with timely, trustworthy, and location-based information. Agricultural extension services are being transformed by the use of ICT such as multimedia technology and other novel methods of interactive knowledge transfer procedures. Farmers have benefited from ICTs by gaining information and increasing their capacity to meet rural and agricultural development goals. Some of the key areas where ICT in agriculture plays a vital role are:

- Regulatory policy and governance
- Agricultural extension and advisory services
- Enhanced market access
- Environmentally sustainable agriculture
- Food safety & traceability
- Financial inclusion and risk management
- Capacity building and empowerment

3. Role of ICT in different aspects of Climate Change

4. Recent Information Technologies in Mitigating Climate Change

Area	Role of ICT	Interventions
Climate Change	Emerging evidence from rural agricultural areas suggests that using ICTs like cell phones, radio, TV, and video to disseminate climate change messaging to vulnerable populations can help in more efficient way. The use of voice-activated and visual apps (e.g., podcasts, participatory community videos, radio, audio-blogs) has become more popular among geographically dispersed, rural populations or communities with a strong oral tradition and low literacy rates. ICTs interventionscontributed to reach and engage wider audiences in climatechange-related topics.(Ospina and Heeks, 2011)	**Initial/Generic Awareness:** ICTs are beingutilized to convey basic information about essential climate change concepts and terminology, as well as to raise awareness of its importance among a broad rural population (e.g. national radio and TV programmes, Internet). **Specific Awareness of Local Issues:** Communication Technologies (CTs) are being utilized to raise awareness of community climate change risks and vulnerabilities, as well as climatic consequences on specific local issues (crop diseases, production levels, water availability, land distribution, and migration are all factors to consider), as well as tailored seasonal forecasts.
Climate change mitigation	ICTs can help analyse the spatial links between carbon emissions and local socioeconomic conditions in rural agricultural contexts, which can help with decision-making and the implementation of incentive-based mitigation techniques.Innovative techniques to analysing various climatic elements can be enabled by applications such as geographic information systems (GIS) and remote sensing technology.	**Agriculture Management:** ICTs that encourage farmers to utilize sustainable agricultural methods (for example, telecentres that provide information on soil conservation and organic farming) help to offset climate impacts on local production and safeguard ecosystems. **Land Evaluation and Use:** Local people can use ICT-based tools and software to pick land with the best production and potential for carbon sequestration under various climatic scenarios for land evaluation and land use planning.

Climate change monitoring	Climate monitoring is inextricably linked to the lifespan of information systems;thus, it can benefit from the practice of information and communication technologies (ICTs) for data collection, processing, and distribution by and among rural populations. In remote areas, ICTs are increasingly being used to map, record, and analyze changes in local resources.	**External Data:** ICTs are used to track climate change using data collected from outside the community (e.g through remote sensing, satellite or aerial photography, meteorological systems, GPS, and modelling etc.). **Local Data:** ICTs are used to track change by collecting and analyzing data on the ground (e.g.,data gathered by community members utilizing smart phones or e-devices to report on forest cover, crop levels and quality, pest forecasting and control, biodiversity etc.) for developing action plans to adopt the climate risk.
Climate change adaptation	The availability, access, and usage of livelihood assets are all linked to vulnerable communities' adaptive capacity. The role of ICTs in climate change adaptation is closelyconnected to the strengthening of agricultural and livestock production systems (e.g., early warning systems, as well as information on pest and disease control, planting dates, seed kinds, and irrigation applications) and the improvement of rural livelihoods (e.g., through improved access to markets) (e.g. using price data, customer patterns, and distribution prospects)(Stienen et al. 2007).	**Vulnerability-Oriented:** ICTs are being used to serve rural agricultural communities' adaptation needs in key susceptibility areas, for example: **Food Security:** ICTs can be utilized to gain access to information about resistant seed kinds and planting procedures, as well as agro-meteorological data for crop protection.

	ICTs are also becoming more important in the delivery of emerging climate knowledge, the facilitation of cross-scale networking (for example, in metropolitan environments, interactions between residents and scientists, diagnosticians, researchers, or government officials etc.), and the implementation of capacity building programmes for local farmers (Braun and Faisal, 2011).	**Water Supply:** ICTs are used to enhance local capacity for water conservation and more efficient water management during the manufacturing process. **Income Generation:** ICTs are being utilized to investigate and get access to alternate sources of revenue, including the fruitful use of ICTs (e.g. to access agricultural markets, prices, or to commercialize products). **Health of crops:** ICTs are used to communicate information on the prevention and treatment of emerging diseases caused by climatic changes, as well as in disease forecasting and control early warning systems. **Climatic Threat-Oriented:** ICTs can be applied to plan and implement adaptation actions targeted at particular climatic threats that affect agriculture and related industries (Disseminating flood prevention information, supporting capacity building for managing extended droughts, knowledge sharing on local implications, or putting in place early warning and response systems are just a few examples for climatic hazards).

4.1 Sensors Driven AI-based Agriculture Recommendation Model for Assessing Land Suitability

Land suitability assessment is one of the most important instruments for developing smart and efficient farming strategies in agriculture. In agriculture, a variety of technologies have been used to collect farm data, which is then processed. The use of wireless sensor networks (WSN) has inspired the development of low-cost tiny sensor devices that can be used for agricultural automation and decision-making. By combining sensor networks with Artificial Intelligence systems, an expert system called Sensors Driven Artificial Intelligence (AI) - Based Agriculture Recommendation Model was created. It uses a neural network and an MLP (Multi-Layer Perceptron) to assess the suitability of agricultural land in four separate judgement classes: more suitable, suitable, somewhat suitable, and unsuitable. The input received from the various sensor devices that are utilized to train the system is used to estimate the appropriateness of agricultural land. This artificial intelligence model can be used to assess future assessments as well as classify land once it has been cultivated (Vincent et al. 2019). Hence this sensor driven AI based agriculture model can help farmers to assess the suitability of land for various agricultural operations in view of farm data (i.e. yield parameters and climatic data).

4.1.1 Monitoring of Agriculture Emission Using Remote Sensing and AI

Particle pollution, ground-level ozone, carbon monoxide, sulphur dioxide, nitrogen dioxide, and other pollutants are being identified using AI to analyze data from IoT sensors and remote sensing data. It is particularly beneficial for analyzing climate change in remote regions where determining the source and volume of pollutants is challenging. The majority of satellites have low geographical resolution and extensive temporal and spatial gaps, making them unsuitable for precise emissions tracking. One of the most successful techniques for detecting biomass burning in the forest is remote sensing. On a global scale, the charred area equipped with remote sensors allows for emission investigation with high temporal resolution (Rolnick et al. 2019).

4.1.2 Deforestation Management

Deforestation tracking systems assist policymakers and law enforcement organizations by providing useful data in cases where deforestation is done illegally. Machine learning (ML) can be used in conjunction with remote sensing imagery to distinguish between selective and clear cutting. Another option is to deploy outdated smartphones in the forest that are powered by solar panels. Within a one-kilometer radius, machine learning may be used to detect and report chainsaw noises (Rolnick et al. 2019).

Unmanned aerial vehicles or Drones are employed to monitor forests in the case of artificial intelligence. Size, payload, sight range, control systems, altitude, and endurance are all factors that can be used to classify drones. Drones' capacity to take exceptionally high spatial resolution imagery at high survey frequencies can be used to collect data from tropical forests. Drone-assisted Community-Based Forest Monitoring programmes can successfully achieve forest management and decentralization of forest data collection (Paneque-Galvez *et al.*, 2014). Preventing tropical deforestation and reducing forest degradation are two climate mitigation options with a huge and immediate global impact. As a result, it has become a topic that is both relevant and typical for global biodiversity protection (Sakr *et al.*, 2010).

4.1.3 Predict Extreme Weather Events

Tornadoes, hurricanes, and severe thunderstorms are examples of high-impact weather phenomena that can inflict major damage to property, infrastructure, and even result in fatalities. The data is transported to data centers via wireless communication technology, where it is processed and measured on the cloud service. Finally, individuals receive information notifications via their smartphones. People receive an early warning message in terms of location, timing, and other weather-related parameters (Maspo *et al.*, 2018).

Artificial intelligence approaches, particularly machine learning, can bridge the gap between numerical model prediction and real-time guidance by boosting accuracy. AI approaches also provide additional decision support to forecasters and consumers by extracting inaccessible information from forecast model output with observations (McGovern *et al.*, 2017).

4.1.4 Efficient Water Management

The injudicious use of water is a great challenge of climate change. Improvements in water use efficiency can reduce the effects of climate change. ICT based smart water management for precision agriculture is being used for an increase in crop yield as well as lowering input cost and achieving environmental sustainability. This also provides the means to operate on the in-field variability as well as connect the variability to various choices for irrigation. With the use of ICT for efficient water management, farmers can also manage application of fertilizers in the form of fertigation. As rice is a water consuming crop, efficient water management is needed to use the resources proficiently.

5. Action Step

Concrete action can be taken to effectively integrate ICTs into climate change responses in rural agricultural areas:

- Focus on income generation as a critical enabler of climate change action and a pillar on which rural agricultural livelihoods may build resilience in the face of growing change and uncertainty.
- Encourage bottom-up approaches to intervention design, implementation, and evaluation that start with understanding the needs and goals of rural agricultural communities and then involve local actors in the development, implementation, and evaluation of programmes.

- Build local communities' ability to take promising action in order to give people innovative tools to deal with change and uncertainty using new and traditional ICTs.
- Plan all of the links between information provision, decision-making, actions, and results, as well as the financial and human resources required to carry out actions at each level of the chain.
- Raising climate change and ICT awareness, providing locally relevant information, and building indicators and action plans based on current and future vulnerabilities can all help to reinforce the foundations.
- Combine multiple applications to maximize the potential of both emerging and classic, digital and non-digital tools in a local setting.
- Enhance traditional knowledge, thereby bridging the gap between scientific resources and indigenous/local practices.
- Integrate climate change and ICTs into livelihood information systems and large-scale development operations to ensure their long-term viability.
- Adopt a process approach that involves beneficiary participation, flexible and phased implementation, learning by doing, and multi-stakeholder support mechanisms. Process techniques include measures to mitigate climate consequences in the short and long term (acute and chronic impacts).

Finally, the ability of local actors and institutions to respond to the challenges and possibilities provided by change is intrinsically tied to the contribution of these ICT tools for climate change awareness, mitigation, monitoring, and adaptation to local agricultural livelihoods (e.g., income and productivity). Financial sustainability, gender and inclusiveness, as well as the evaluation and monitoring of ICTs' role in climate change processes, are just a few of the essential issues that need to be investigated further through academic study and practical experience.

6. Conclusion

Despite the fact that much remains to be learned about the role and potential of ICTs in the field of climate change, the findings presented here illuminate key conceptual foundations that aid in better understanding the complex interconnections that exist within vulnerable livelihood systems, and that ultimately determine the role of digital technologies in achieving development outcomes in the face of an uncertain climate future. It is possible that, in the event of climate change-related shocks the system's ability to respond through adaptation can be increased through ICT interventions. It may be used to investigate the possibilities and constraints of ICTs' participation in adaptation processes, as well as to facilitate the identification of methods that can help improve adaptive capacities and, ultimately, development outcomes in the face of long-term climate unpredictability.

Finally, the ability of local actors and institutions to respond to the challenges and possibilities provided by change is intrinsically tied to the contribution of these

ICT tools for climate change awareness, mitigation, monitoring, and adaptation to local agricultural livelihoods (e.g. income and productivity).

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