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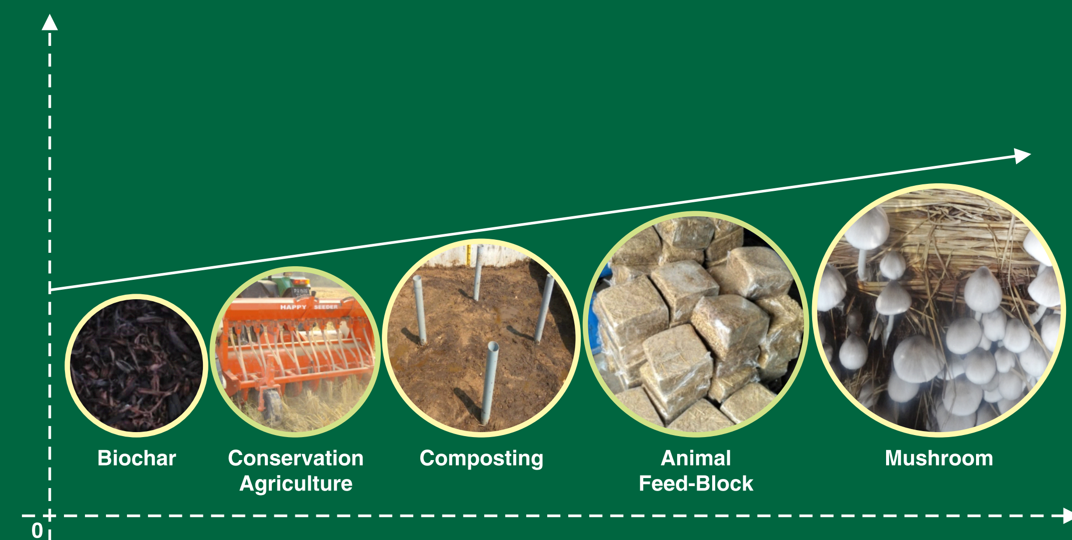
Gainful Disposal of Rice Straw: Eastern Indian Perspective

P Bhattacharyya, D Bhaduri, S Munda, J P Bisen, B S Satapathy, B C Verma, A K Nayak, A K Mukherjee, P Panneerselvam, S Lenka, S Priyadarsani, P K Dash, N T Borkar, P Swain



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Preface

There are about 731 million tons of lignocellulosic rice straw generated in the world every year. Every kilogram of harvested rice is accompanied by production of about 1.0-1.5 kg of the straw. Assuming that 50% of crop residues are utilized as cattle feed and fuel, the nutrient potential of the remaining residue is 6.5 million tonnes of NPK per annum. In India about 16% of generated crop residues are burnt on farms.

Recent estimate showed that during November-December, around 70% cause of air pollution in New Delhi and its surrounding cities was straw burning. Not only Punjab and Haryana, straw burning is spreading over other states, very rapidly. Primarily burning causes emission of CO2, CO, SOx, NOx, particulate matter and CH4 which increases air pollution and GHGs/ Carbon footprint tremendously. It is a paradox that on one hand we have a shortage of animal feed, biofuel and manures, and on the other hand considerable amount of crop residues are either wasted or burnt. This is not only a big loss of natural renewable resources but at the same time it is a source of greenhouse gas (GHG) emissions and environmental pollution. However, these residues can effectively be used as mulch, for production of manure, ethanol, bio-diesel, biochar, etc., and in conservation agriculture. There are knowledge gaps on the economic technologies for in-situ and ex-situ composting of straw, characterization of rice straw of available varieties for various purposes, cost-effective small-scale technologies for bio-energy production, technologies for value addition of paddy straw in view of present day mechanized agriculture and authentic database on contribution of straw burning in air pollution and GHGs/ carbon footprint.

In this research bulletin **'Gainful Disposal of Rice Straw: Eastern Indian perspective'**, we have attempted to document the various avenues of rice straw utilization especially in the context of Eastern India. This is not only cut-off the chances of GHG emission but also secure the economic return of farmers. By analysing the root of the problems and understanding the environmental and economic consequences of open field burning of rice straw, various practical and profitable options utilizing the rice straw were suggested. Our own research findings on mushroom production, biochar and straw-based compost was presented along with the step-by-step procedure, characterization and benefit:cost analysis. Grouping of varieties based on biochemical analyses, surface morphology and functional groups as identified by authors was also discussed along with future course of action, considering the scenario of Eastern India. Some case studies from Odisha farmers were also mentioned who are not wasting the resource of rice straw and suitably employed for income generation in either of the forms.

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Authors

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1. Introduction

In India, the rice straw production is around 126.6 million tons by considering average harvest index of 0.45%. However, presently due to lack of economically viable options of rice-straw utilization farmers in India, especially from the north-western states namely, Punjab, Haryana and western-Uttar Pradesh become compelled to burn the straw in fields itself. Around 16% of crop residues are subjected to burn on field in India out of which 60% is rice straw. Especially, rapid adaptation of photosensitive varieties of wheat and rice have intensified the rice-wheat cropping system in N-W India, as a result, the farmers get a small window (20-30 days only during October-November between rice and wheat crop to prepare their field and therefore opt for straw burning. Further, majority of rice cropping area is harvested using combined harvester which spreads the rice residue in the fields which is difficult to collect and handled. Most of the farmers do not possess the essential machineries like happy seeder, super seeder, reversible mould board plough etc. for in-situ management of paddy straw and they have a limited time window for preparation of land for the next rabi crop. However, rice straw burning is spreading rapidly at an alarming rate in India. Open field straw-burning has harmful environmental effects including air pollution and greenhouse gases emissions.

The eastern Indian states lags the agriculturally leading western and southern Indian states. On the other hand, these states account for 58% of rice area and 59% of annual rice production in the country and cumulatively generates about 90 MT of rice straw annually (59% of gross national production) (Fig. 1). These states account for about half of the Indian cattle population while their total farm income as a share of gross household income ranges from 24-63 percent [Chattisgarh (63%), Bihar (47%), Jharkhand (29%), Uttar Pradesh (57%), Assam (63%), Odisha (28%) and West Bengal (24%)]. Several academic and policy literatures on rice straw have reported on the

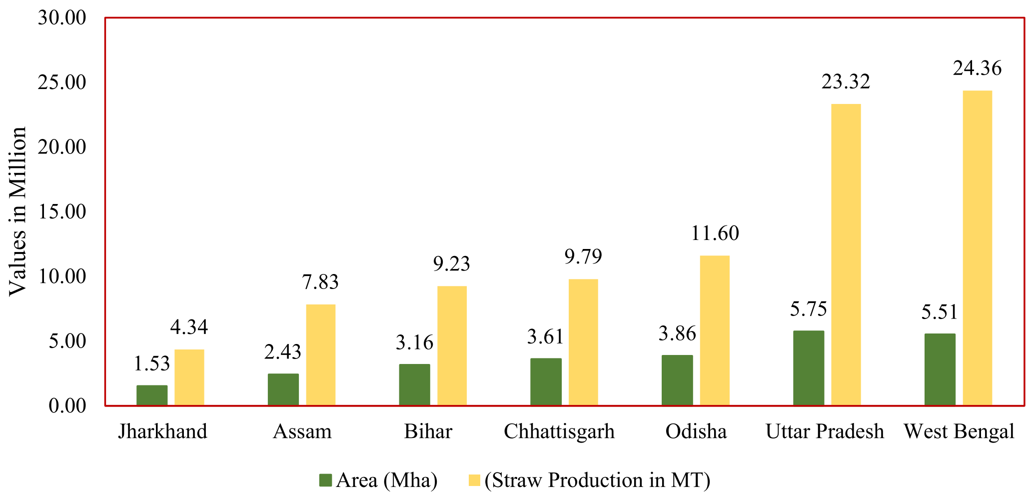


Figure 1: Rice area and straw production in eastern- Indian states (2018-19)

mineral composition of the straw (Dobermann and Fairhurst, 2002; Japan Institute of Energy 2002; Barmina et al. 2013) and many others have reported on the economic and environmental consequences of straw burning. Open field straw burning worsens the local and regional environment affecting the human and animal health; soil micro flora and fauna (soil biodiversity) (Kumar et al., 2015; Bhattacharyya et al., 2021). Contrary to it, the other guild of researchers is looking for how such mis-management practices can be reversed to economically benefit the farmers and other stakeholders.

In Indian agricultural research system, Indian Council of Agricultural Research (ICAR), National Agricultural Research and Education System (NARES), National Academy of Agricultural Sciences (NAAS) and other State Governments Functionaries across the country have been taking initiative to answer the basic question, "how to dispose the straw gainfully without jeopardizing the environment and economics?" To answer this question an attempt was undertaken by ICAR-National Rice Research Institute (NRRI), Cuttack in a flagship project on rice straw management started during the year 2017. These basic objectives were to identify the root cause behind the straw burning, major challenges and opportunities of alternative *in-situ* and *ex-situ* management. In this research bulletin we attempt to advocate the major policy question – ***"how to gainfully manage the rice residue in the country with special emphasis on the eastern states of India?"***

1.1. Understanding the Cause

The north-western Indian states remain the main focal point of green revolution in the country in middle years of 1960s. The skewed focus on this NW region led to selective build-up of agricultural infrastructure (input markets, irrigation infrastructure, output market, procurement, storage, and logistics infrastructure among others) and percolation of subsidies (free electricity for irrigation) and farm mechanization led to rapid growth in farm output of the region. Complemented by White revolution in the western India, it further added to prosperity of farm households in the region. Assured irrigation developed input and output markets and procurement machinery are few of the factors contributed for crop intensification in spatial and temporal dimensions. In toto the spatial and temporal crop intensification has proven boon to food and nutritional security of the nation; however, the byproduct of temporal intensification is that it has imposed negative social and environmental externality by depleting the soil and air quality. Growing more crop on a same piece of land to fulfil the augmenting demand depleted the inherent fertility of the soils and pressurized land resources. Further limited time between harvest of kharif rice and sowing of rabi crops (particularly wheat in N-W India), reduction in the cattle population and subtle farm income provided substantial grounds for restrained residue maneuvering ability of the farmers. Moreover, the geographic and anthropogenic factors like concurrence of trade winds/jet stream (westerlies) from west, wet, and heavy moisture ladened winds, emission from residue burning in NW India and Himalayan barrier also fueled the problems by intensifying the health and environmental challenges of pollution in Delhi and National Capital Region (NCR). However, the burning of rice residue due to limited maneuvering ability in the NW region of India has set a precedence for other regions too. Currently, even the eastern and central Indian states among other are resorting to the same owing to savings in time and monetary resources at the cost of environmental externalities. Amidst these developments, the most concerning issue is that despite the cropping sequence has substantially metamorphosed over the period, the institutional and managerial capacity of the agricultural ecosystem has not parallelly transformed to accommodate for such changes.

1.2. Environmental consequences of open field burning (OFB)

Among the different ex-situ management alternatives open field burning (OFB) of straw is detrimental to the environment because of harmful emission and environmental pollution. The emission includes poisonous gases (carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen oxides (NOx), gaseous hydrochloric acid (HCl), volatile organic compounds (VOC), carcinogenic polycyclic aromatic hydrocarbons (PAH), dioxins and furans etc. and particulate matters (Oanh et al., 2011). These poisonous elements of emission are detrimental to the health of residents in the surrounding area of high atmospheric concentration of pollutants. Also, the OFB adds suspended particles (like $PM_{2.5}$ and PM_{10}) responsible for deteriorating the air quality. Apart from these, OFB of one kilo gram (kg) of dry rice straw loads the environment with 700-4100 mg of methane (CH_4) and 19-57 mg of nitrous oxide (N_2O) (Kritee et al 2018; Islam et al 2018; Josh G. 2018 and Anonymous 2018).

1.3. Economic consequences of open field burning (OFB)

Economically, the increased input cost due to substantial losses of plant nutrients like nitrogen (~40%), potassium (~33 %) and sulphur (~45%) and loss of soil microbial biodiversity concerns farm income and farm households prosperity in south-east Asia and specifically in India (Dobermann and Fairhurst, 2002; Bhattacharyya et al., 2019). Further, the depleting soil resources are associated with increased intergenerational inequality in reaping the equitable benefits from the land resources and burdens the future generation with sustaining and maintaining the soil fertility which would have negative implications on their economic capabilities.

1.4. Dividends from in-situ and ex-situ management of crop residue

The Indian agricultural ecosystem generates major crop residues like cereal and millets residues (rice, wheat, maize, sorghum, other minor millets etc) and residues from pulses, oilseed crops (Mustard, sunflower stalks etc), cotton (stalks), jute (sticks), sugarcane (trash, and press mud) etc. Annual crop residue generation from rice in India varied from 122 to 341 MT over the years (1994-2015) shown wide variability (Table 1) (Agarwal 2007; NAAS, 2012; GoI, 2014; Jain et al., 2014 and Devi et al., 2017). However, there exist various approaches for the effective management of such by-products from the cropping system which are categorized into *in-situ* and *ex-situ* management approaches. In-situ management approaches include those methods which manages the crop residue on the place of its generation itself in economically and environmentally sustained manner like soil incorporation, soil mulch among others. While the ex-situ management methods resorted on lifting and transporting such residues from the places of its generation and its effective disposal among various ends in economically and environmentally sustainable way.

The economic dividends of both the in-situ and ex-situ management methods owe to the lesser input and pollution abatement cost for the farmers and society. Soil incorporation of residue enhances the soil C:N content; adds to carbon sequestration; improves soil structure; water holding capacity of the soil and preserve the soil microbes. While the soil mulching checks the loss of soil moisture and thereby enhances soil moisture for crop growth and development and help in soil solarization which is crucial for soil sterilization. These dividends strengthen the soil fertility and reduces the dependence on extraneous inputs and thereby reduces input consumption expenditure (on fertilizers, irrigation, pesticides and other soil amendments among others) and are thus vital for supporting farm income. Further, savings of society on medical expenditure due to respiratory health problems caused by the pollution is another positive externality of efficient residue management. On the other hand, maintaining land resources, soil structure and fertility, reduced pollution and conservation of soil biodiversity are another environmental dividend. These dividends seems to have slower but long-term positive implication for the environmental sustainability as they contribute to regulating the nutrient cycling and maintaining the resource flow in the ecosystem.

2. Factors encouraging Open Field burning (OFB)

This section attempts to answer the question i.e., *"whether the residue burning is choice of farmer or he do it out of compulsion?"* Our study including the primary survey and review of literature revealed that, the subsistence farm income in eastern-India is an important prohibitive factor for the farmers to undertake any investment which would not have any direct and visible impact on their net returns in short run. The myopic insight of farmers (due to inflated cost); short run personal gain over long tern societal cost and inherently limited capacity (due to small land holding, meagre farm income and inflating input costs); poorly developed secondary market for the farm support services (skewed farm mechanization in favour of land preparation and harvesting) and inadequate external incentives (affordable logistics for transporting the residue to power generation plants and lack of entrepreneurial infrastructure among other) are some of the compelling factors which impose severe restrictions on the choice of the farmers for proper disposing off the residual wealth.

Table 1. Constraints faced by farmers in management of rice residue in India

S. No.	Reported Constraints	Researchers/Studies
i	Short time between harvest of *kharif* rice and sowing of *rabi* crops (particularly wheat in N-W India)	Gadde et al., 2009; Kumar et al 2015; Chendrashekhar et al., 2018
ii	Shortage of labour and high labour-cost	Tado 2017; Chendrashekhar et al 2018; Kaur, 2017
iii	Problem of land leveling after residue incorporation in soil	Chendrashekhar et al., 2018
iv	Small land holdings for adoption of sustainable technologies	Chendrashekhar et al., 2018
v	Relatively costly rice-straw management practices compared to burning	GoI, 2013; Chendrashekhar et al., 2018; Kaur, 2017
vi	Inadequate timely supply of custom hiring services for straw-management machineries (Happy-Seeder; Rotavator; Baeler; Chopper; Zero-till-Seed Drill etc.)	Sidhu et al., 2007; Chendrashekhar et al., 2018
vii	Unwillingness of farmers to put extra effort for composting of straw	Chendrashekhar et al., 2018
viii	Lack of technical knowledge among the farmers/ stakeholders about *in-situ* straw management	Chendrashekhar et al., 2018; Tado, 2017
ix	In present scenario the rice-straw has limited economic-value to the farmers	Gupta, 2012; Chaudhary, 2018
x	Decreasing demand of rice straw for cattle feed	Sidhu et al., 2007
xi	Drastic reduction in demand of rice straw for thatching	Sidhu et al., 2007
xii	Lack of economically viable alternatives for *ex-situ* straw management	GoI, 2014
xiii	Lack of logistics and storage for handling the huge amount of straw in short time	Tado, 2017; Chaudhary, 2018
xiv	Rapid enhancement of intensive agriculture and increased mechanization	Chaudhary, 2018
xv	Limited and unorganized market for rice-straw	

Source: Bhattacharya et al. (2021)

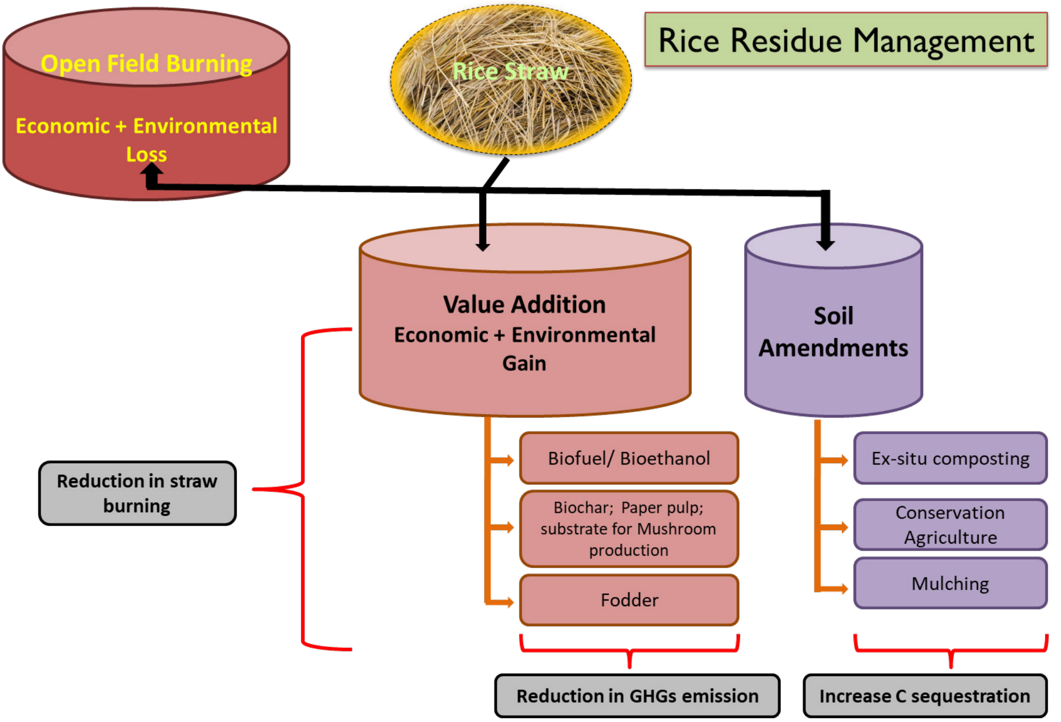


Figure 2. Schematic diagram representing the avenues of alternate management of rice residues for securing both economic and environmental gains

3. Chemical characterization of rice straw for potential uses

Based on the study conducted by the team of authors, popularly grown 18 varieties in eastern India had been characterized for the parameters like biochemical analyses (cellulose, hemicellulose, lignin and Si), surface morphology by scanning electron microscopy (SEM), functional group analysis by FTIR. The varieties selected were Tapaswini, Sahabhagi, Naveen, Swarna sub-1, Geetanjali, Durga, Abhisek, Sarala, MTU-1010, Ketakijoha, Satabdi, CR-310, Pooja, Vashadhan, Gayatri, Ratna, IR64, Kalajeera, Swarna.

Table 2. The basis of grouping of straw for their potential uses

Products	Desirable features of Straw
Bioethanol	a. High Hemicellulose or High Hemicellulose and Cellulose b. Low to medium lignin and Si c. C=O, FTIR (hemicelluloses Group)
Biochar	a. High Lignin b. Low to Medium Cellulose and Hemicellulose. c. High Aromicity (aromatic group in FTIR; more Syngil moiety) d. High silica grooves and low surface area

Compost	a. High to Medium Cellulose b. Low to medium Lignin and Silica c. Low silica grooves and High surface area d. Broad –OH bond (FTIR)
Mushroom	a. High to Medium Cellulose b. Low Silica c. Low silica grooves and High surface area d. Broad –OH bond (FTIR)

Based on commonality and differences of the above-mentioned parameters, those 18 varieties were clustered for alternate potential uses to reduce the load of straw burning. Considering all three feature of morphology, functional groups and biochemical parameters, cultivar Tapaswini found best suited for bioethanol conversion from rice straw. Straw of rice cultivar IR 64 found best suited for rice straw biochar conversion while Tapaswini and Swarna were grouped as best suited compost. Sarala, Gayatri, Tapaswini and Swarna Sub1 out of 18 cultivars tested, suitable for rice-straw mushroom cultivation (Bhattacharyya, et al. 2020).

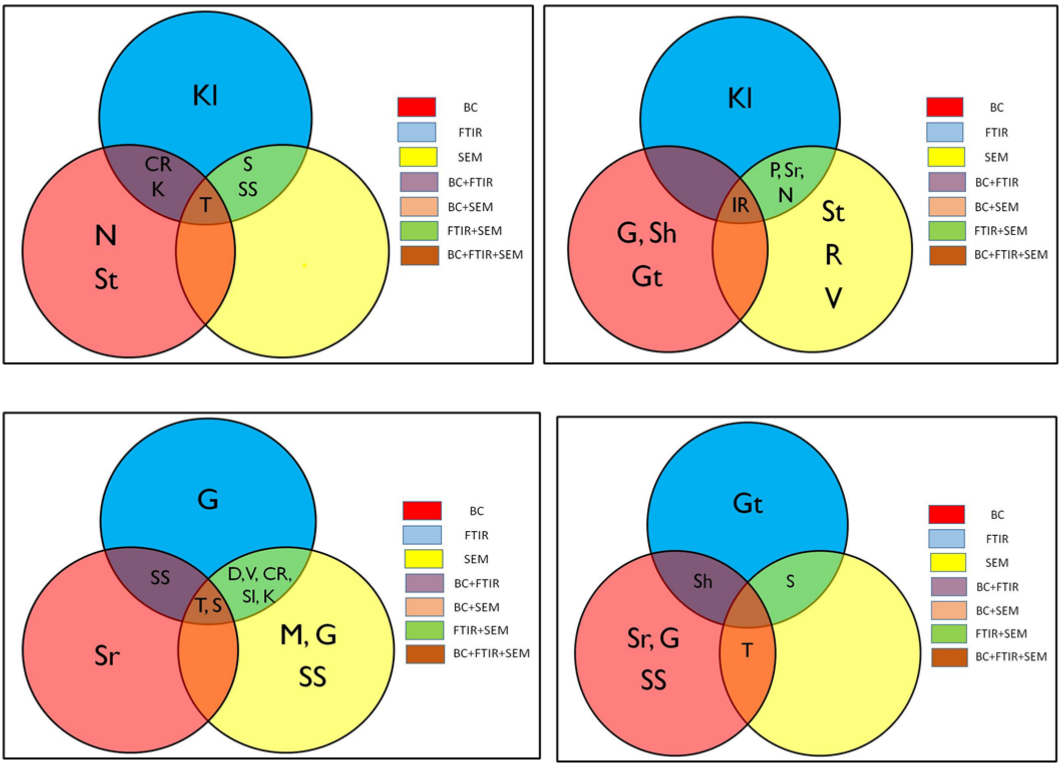


Figure 3. Categorization of 18 rice cultivars for (a) Bioethanol, (b) Biochar, (c) Compost and (d) Mushroom production based on Biochemical, FTIR and SEM analysis.

4. Paddy Straw -Mushroom

Cultivation of edible mushroom is considered as one of the cheapest and economically viable processes for the bioconversion of lingo-cellulosic wastes. Mushrooms have capacity to convert nutritionally less valued substances like paddy straw in to a valuable and nutritious human food and animal feed. Over the years, mushroom has gained popularity due to: short production period, suitable for indoor and outdoor production, gender-friendly, high market demand and protein source for vegetarians. Low calorific value, high biological efficiency, rich in protein, vitamins and minerals are mushroom's nutritive quality.

Mushrooms are macro fungi and recognized by FAO as nutritional food for the poor people of the under developed countries. In India, about 0.13 mt of fresh mushroom produced annually out of which share of button mushroom is 73% followed by oyster mushroom (16%), paddy straw mushroom (7%) and milky mushroom (3%).

Generally, there are three different types of mushrooms in India which utilize paddy straw for cultivation:

1. Button mushroom (*Agaricus bisporus*)

2. Oyster mushrooms (*Pleurotus spp.*)

3. Paddy-straw mushroom (*Volvariella volvacea, V. diplasia*).

Figure 4. Oyster mushroom (left) and Paddy straw mushroom (right)

Paddy straw mushroom (*Volvariella* spp.) is also known as 'warm mushroom', grown within a shorter life cycle (14 days) and commercially popular in the states of Odisha, Andhra Pradesh, West Bengal, Kerala and Tamil Nadu. Oyster mushroom (*Pleurotus* spp.), commonly known as 'Dhingri chhatu' in Odisha, is cultivated in winter months (November-February). This has higher biological efficiency (100%), better shelf life (24 hours), but needs more time for completion of its life cycle (45 days).

It is an age old practice when commercial mushroom cultivation has relied on rice straw as base materials and the required energy source. In this context, organic matter turnover and the transformation of silicon content in rice straw (as soil like substrate) during planting, and the growing of mushroom needs to be optimized. Higher Si in rice straw has been a barrier to decompose the cellulosic and lingo-cellulosic materials, and to extract the nutrients for the survival of living body grown over it (here, mushroom). Mushroom substrate may be defined as a kind of lignocellulose material which supports the growth, development and fruiting of mushroom (Chang and Miles, 1989; Baysal et al., 2003). Oyster mushroom may be grown on wide range of plant waste as substrate e.g. sawdust, paddy straw, sugarcane baggage, corn stalk, corn cobs, waste cotton, leaves and pseudo stem of banana, water hyacinth, duck weed, rice straw etc. does not require costly processing method and enrichment material (Salami and Bankole, 2018). Hence, it is preferred to take cultivars for mushroom cultivation of higher to medium cellulose with lower Si content.

Why is rice straw preferred as substrate for mushroom cultivation?

- Rice straw is most easily available after harvesting of rice crop in the months of late October to late November.
- Rice straw mushrooms, *Volvariella volvacea*, are considered to be one of the easiest mushrooms to cultivate because of their short incubation period of 14 days.

What are the benefits of straw mushroom?

- Excellent flavour
- Short cropping cycle
- Outdoor cultivation is possible
- Biological efficiency: 15 %
- Shelf life: 12 hours

Figure 5. Paddy straw mushroom: initial to final stage

How to select the suitable rice varieties for mushroom production?

The physical and chemical properties of rice straw vary with variety, harvest time, method of threshing and season of rice crop which influences the quality and productivity of mushrooms. There is consistent variation in the nutrient value of rice straw associated with location and season for rice cultivars. Hand threshed rigid and tall rice straw was found to be more appropriate than dwarf cattle threshed and flexible straw against V. esculenta. Cellulose/lignin ratios in rice straw were positively correlated to mycelial growth rates and mushroom yields. The physical properties (moisture content, particle size, bulk density and porosity of rice straw varies with rice varieties even though they were grown under same climatic conditions using same soil type and cultivation methods. The role of extracellular enzymes like cellulases, hemicellulases and lignases is pivotal to the production of any mushroom fruiting body which is affected by the various nutrients and physical factors of substrates used.

Experimental finding reveals that straw of rice varieties rich in cellulose and poor in lignin content favours mushroom production. Rice varieties like CR Dhan 310, Swarna sub 1, Pooja, Swarna, Varshadhan CR 1009, CR 1018, Lalat, Kalachampa are found more suitable for commercial production of paddy straw mushroom in coastal districts of Odisha. Similarly, CR Dhan 205, CR Dhan 206 and Lalat found suitable for production of Oyster mushrooms in winter season in hilly regions of Odisha. Authors own findings suggests that Sarala, Swarna-Sub1, Swarna and Pooja are the most suited varieties for mushroom production based on the biochemical analyses (cellulose, hemicellulose, lignin, Si), surface morphology of straws through Scanning Electron Microscopy (SEM), and presence of functional groups by Fourier Transform Infrared (FTIR) spectroscopy (Bhattacharyya et al. 2020). There is a great scope to evaluate the predominant rice varieties and available rice germplasms to establish the rice varieties most suitable for economic and environment-friendly utilization of rice straw for value addition.

Hence ideal characters of rice straw for mushroom cultivation are:

- High to medium cellulose
- Low silica
- Low silica grooves and high surface area
- Broad –OH bond as functional group

Where are the possible places to grow paddy straw mushroom?

A. Low-cost thatched house

B. Temporary shed

C. Mushroom cultivation under coconut orchard

Figure 6. Different mushroom growing conditions in Odisha

How best mushroom can be produced in small set up?

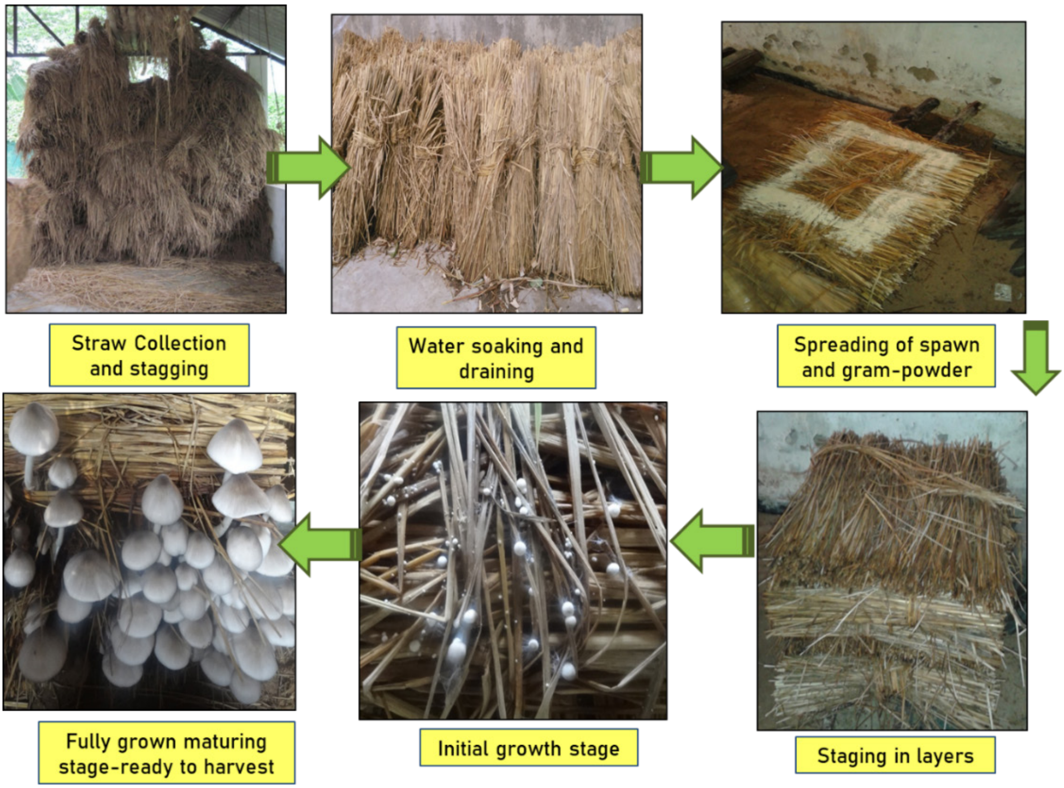


Figure 7. Step-by-step pictorial flowchart of mushroom production utilizing rice straw

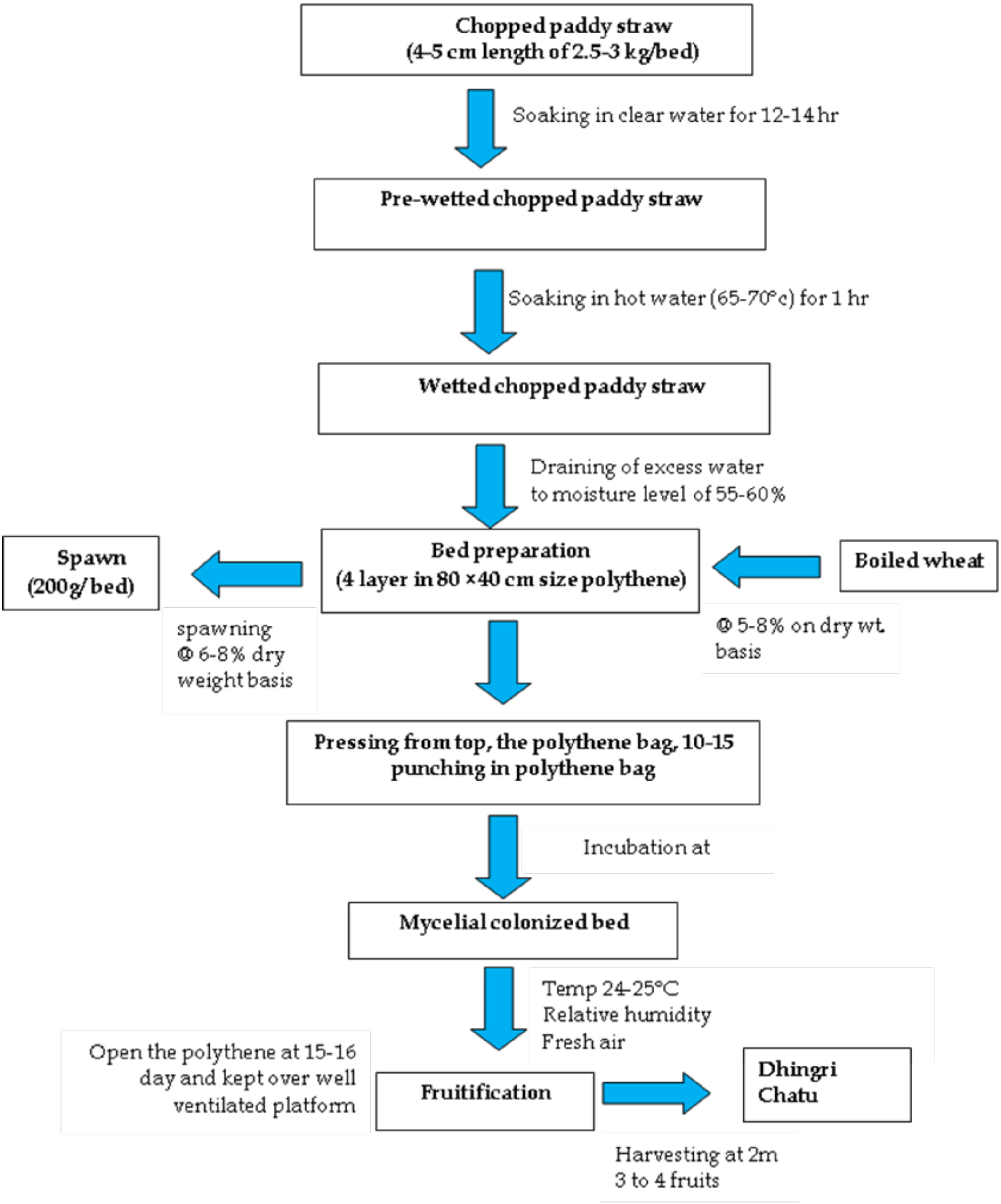


Figure 8. Cultivation technology of Dingiri chatu (Pleurotus spp.)

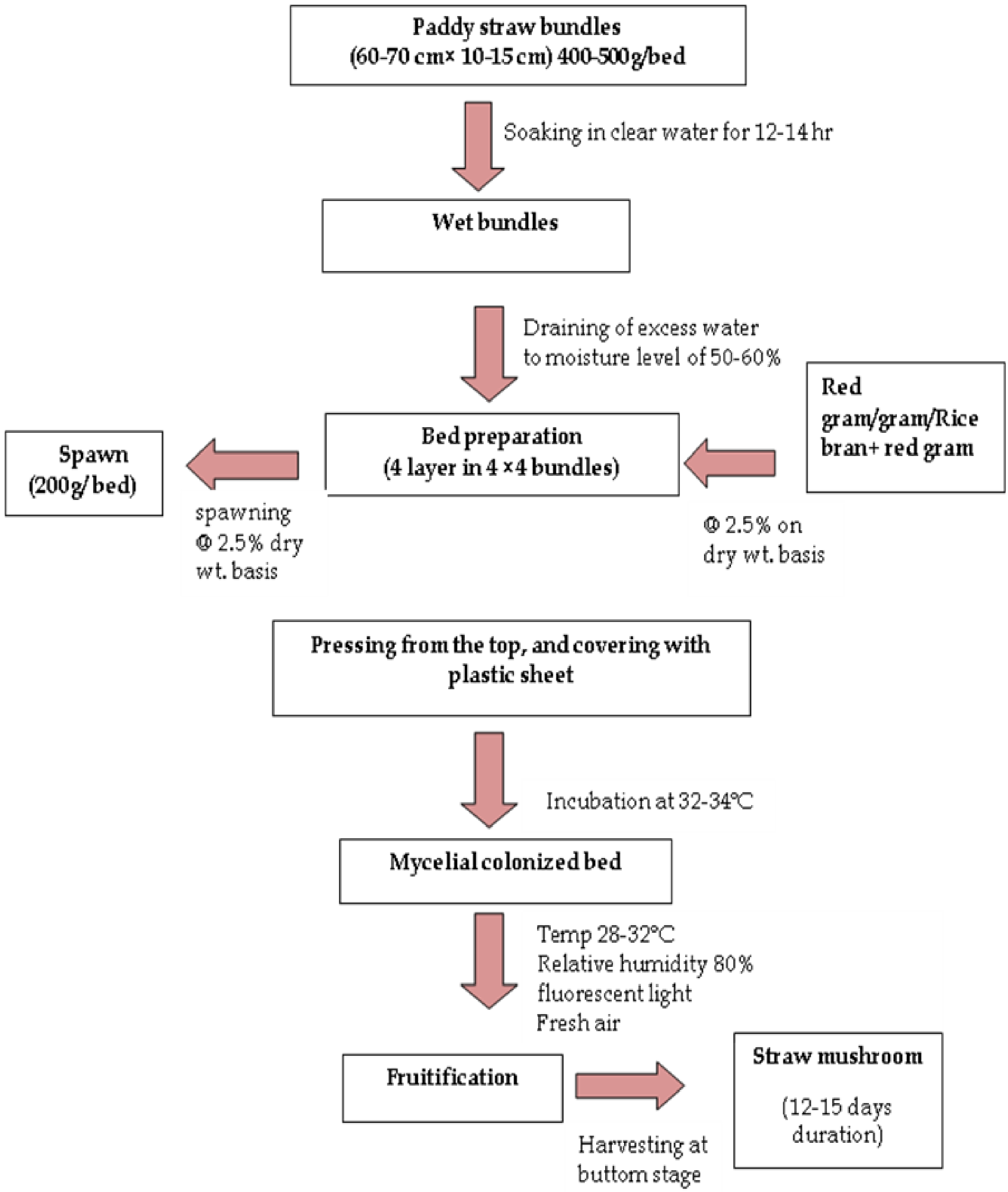


Figure 9. Cultivation technology of Paddy straw mushroom *(Volvariella volvacea)*

Figure 10. Mushroom production utilizing rice straw for experimental purpose at the net house of ICAR-NRRI (Cuttack)

How to do the post-harvest operations?

- For mushroom production, it is better to harvest the rice crop at maturity close from the ground leaving bottom 10-15 cm stubbles.
- Manually harvested and threshed paddy straw bundles having less than 12% moisture, free from any mold and properly stored for few months are suitable for paddy straw and Oyster mushroom production.
- After harvest, the crop should be toughly dried under sun in the field itself for 2-3 days depending upon the available sunshine in the locality.

- After drying the harvested crop should be transported to the threshing floor by making bundles of 10-15 cm diameter.
- Bundles of harvested rice may be threshed by manually beating on hard surface or by using pedal operated/electric operated manual thresher.
- After threshing the bundles have to stake on heaps in a protected space for better storage. About 5000-6000 bundles can be harvested from one hectare of rice crop.
- Good quality packaging before marketing and it is important for consumers' point of view.

Figure 11. Women farmers in Odisha are involved in mushroom cultivation as an allied-agriculture activity and alternate employment generation

What are the Environmental benefits?

- Use of rice straw for mushroom production is a win-win situation where, we can convert a waste (burned rice straw to ash) to an asset (substrate for a high value mushroom).
- As compared to burning, the same amount of rice straw, GHG emissions due to mushroom cultivation is much lesser.

What are the Socio-Economic Impacts?

Utilizing excess rice straw for cultivation of paddy straw mushroom is an eco-friendly and economically feasible approach. Odisha is presently contributing 10% of India's total edible mushroom production. Ideal climatic condition and food preference favour mushroom cultivation in Odisha. Almost all districts of Odisha are suitable for mushroom cultivation. This is more suitable for small and marginal farmers as an agriculture-allied activity to secure farm income with low investment. Farmers of tribal belt in Odisha can practice mushroom cultivation to generate employment, sustain household income and to meet nutritional requirement of own family.

Farmer can use on own paddy straw for mushroom production. An estimated economics of mushroom production at farmer's field are briefed in Table 1. A farmer can take conveniently 100 mushroom beds and will get around Rupees 2.20 for every one rupees invested. By utilizing own saved paddy straw and family labour a farmer can earn about Rs 5/- for every one rupee invested in a period of 15-45 days only.

Figure 12. Mushroom as a component of rice-based farming system in Puri districts of Odisha, Pooja, Swarna and Swarna Sub-1 are popular for mushroom production

Table 3. Economics of mushroom production by using paddy straw (100 beds each)

Particulars	Paddy straw mushroom		Oyster mushroom	
	Quantity	Amount (Rs)	Quantity	Amount (Rs)
Paddy straw	1600 bundles	3200.00	3.0 kg (6-7 bundes)	15.00
Spawn	100 bottles (200 g)@ Rs 15/bottle	1500.00	100 bottles (200 g) @ Rs 15/bottle	1500.00
Supplements	Gram flour/besan/ rice bran+ gram flour 20kg	2000.00	Wheat 20kg@ 40/kg	800.00
Polythene	100 sqm @ 8	800.00	100 nos@ Rs 4	400.00
Miscellaneous		500.00		800.00
Labour	10 MDYS	2500.00	12 MDYS	2500.00
Total operational cost		10500.00		5565.00
Gross return	200 kg @ 2 kg/bed @ 120/kg	24000.00	200kg @ 60/kg	12000.00
B : C ratio		2.28		2.16

5. Rice Straw- Biochar

What is biochar?

Biochar is charcoal that is produced by pyrolysis of biomass viz., rice straw, in the limited presence of oxygen, and is used as a soil ameliorant for both carbon sequestration and soil health benefits. Biochar is a stable solid that is rich in carbon and can stay in soil for long time (hundreds to thousands of years).

What the properties are of rice straw derived biochar (SDB)?

Straw derived biochar has many interesting properties. It is strong adsorbent and holds water, metals, and organic chemicals. The highly porous physical structure of SDB provides habitat for microorganisms when applied to soil. With so many different properties, SDB is bound to have a lot of different uses, but one function that makes SDB a unique material is carbon sequestration. SDB contains about 50% of stable aromatic carbon. By fixing easily degradable plant carbon into aromatic carbon, carbon dioxide is slowly but surely removed from the atmosphere.

What is the potential uses of straw derived biochar?

After the harvest of rice crop, huge quantity of rice straw is burnt in open fields leading to air pollution. Rice straw can be effectively used as raw feed material for biochar production. There are various goals for utilization of SDB. It has high potential to be used as soil amendment to improve soil quality and subsequent yield. However, other than soil application biochar can be used for many other purposes. Those are, drinking water filtration, sanitation of human and kitchen wastes, and as a composting agent. It also used as adsorber in functional clothing, insulation in the building industry, as carbon electrodes in super-capacitors for energy storage, food packaging, wastewater treatment, air cleaning, silage treatment agent and/or feed supplement.

How to derive the rice straw-biochar at small scale?

The biochar can be produced by pyrolysis of straw at 300-400°C for 3-4 hours using indigenous furnace or kiln at controlled temperature and restricted aeration (Fig. 13).

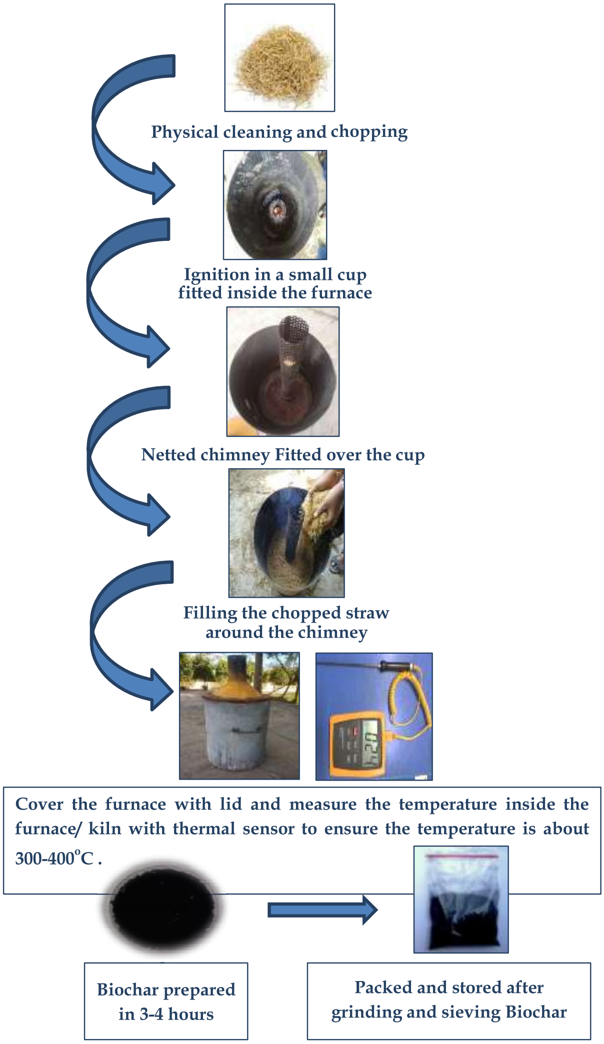


Fig 13. Procedure for preparation of biochar from straw

Steps for biochar preparation

1. Collection of straw from field after rice harvest
2. Physical cleaning of straw by drying the straw and beating it to remove the small mud clods and chopping/ cutting it to desirable length.
3. Igniting a small quantity of wood at the bottom of the furnace and fit the netted chimney suitably to restrict the flow of oxygen.
4. Fill the furnace with the straw and pack it completely around the netted chimney.
5. Cover the furnace immediately after packing with double lid.
6. Ensuring the temperature inside the furnace/ kiln is about 300-400oC by regular monitoring with thermal sensor.
7. Stable biochar could be prepared in 3-4 hours.
8. Taking out the biochar out from the furnace after the furnace is sufficiently cool to handle.

How did recovery efficiency of biochar vary among rice varieties?

Biochar from straw of nineteen popular rice cultivars was prepared at two different durations (2 hours and 4 hours) at a fixed pyrolysis temperature (300°C) in an O2-free environment and pre-fixing all other preparatory criteria. It was observed that weight loss after heating varied from 25% (Varsha Dhan) to 91% (CR 310) and for major number of cultivars, yield of biochar ranged between 50-70% while the pyrolysis was undergone at 2 hours pyrolysis duration. At 4 hours pyrolysis duration the situation was vice-versa i.e. percent weight loss of the biomass was more while the biochar yield was less. The biochar yield obtained was as low as 10% (Swarna sub-1) to as high as 52% (Ratna) after 4-hours pyrolysis (Bhaduri et al. 2019).

Figure 14. Rice straw biochar prepared under controlled heating and temperature

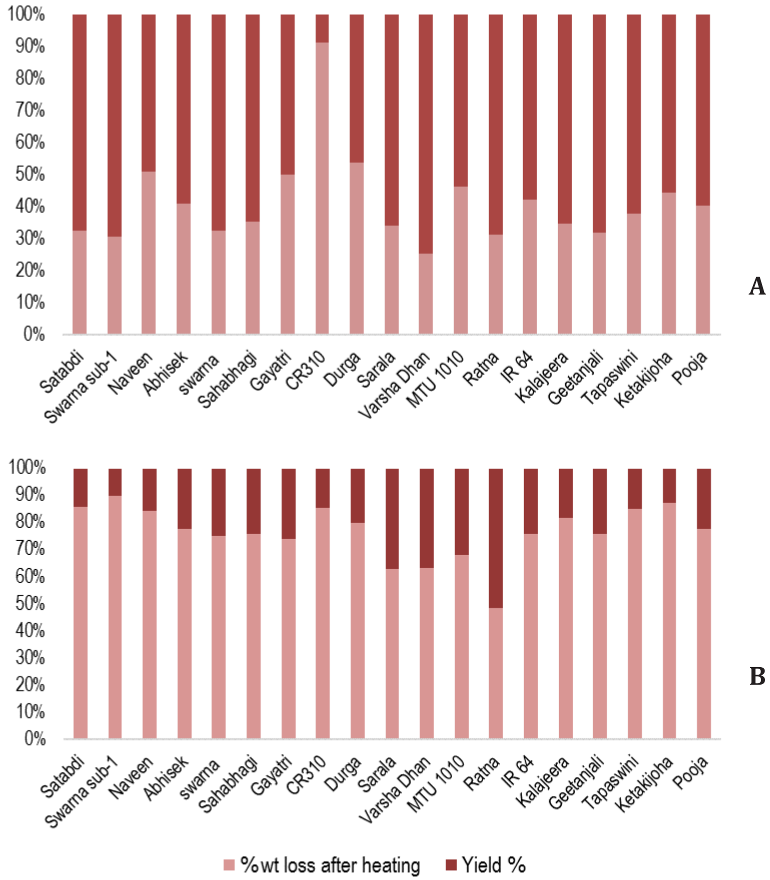


Figure 15. Yield and weight loss of the Biochar produced from nineteen rice cultivars (A. 300°C for 2 hours, B. 300°C for 4 hours)

How and how much to apply straw derived biochar in soils for crop production purpose?

Rice straw derived biochar (SDB) can be applied at a rate of 2 tha-1 to 10 tha-1depending on the soil needs (physicochemical status), SDB availability, and feasibility. Rice crop yield improve with application rates of 2 tha-1and above. In soils with high acidity, the application rates need to be higher to bring the soil to neutrality to achieve an optimum soil condition for crop production. Application of 10 tha-1or more may be required only in acid soil with pH<5.0. Earlier, long terms experiment (>5 years) conducted with rice husk derived biochar suggest that higher doses in neutral soils do not have any negative effect on grain yield or soil properties.

In an experiment (ICAR-National Rice Research Institute), when SDB was applied with recommended dose of fertilizers, it improved the grain yields significantly compared to sole application of fertilizers at recommended dose (RDF). Application of SDB @ 2 tha-1 to 8 tha-1 was found to increase the yield to up to 25%.

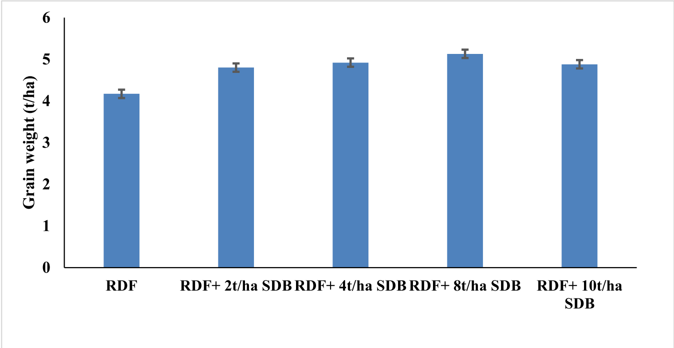


Figure 16. Grain yield (t ha^{-1}) of rice as influenced by rates of straw derived biochar (SDB)

How much increase in soil quality and crop yield is possible?

Addition of SDB to the soil adds soil organic carbon (SOC) and available nitrogen (N) content at various quantities. The degree of accumulation depends on soil type, soil management practices, rate of application and the frequency of application. An experiment was carried out at ICAR-National rice Research Institute in a lowland rice soil for four years. The soil is characterized as sandy clay loam (30% clay, 18% silt and 52% sand), classified under Aeric Endoaquept (USDA). The results indicated that the 50% increase in SOC is possible with application of SDB (10 tha-1) in addition to the recommended doses of fertilizers (RDF) for four consecutive years (Fig. 17). Similarly, available N increased by about 9% and 25% with 2 t ha^{-1} and 10 t ha^{-1}, respectively, compared to the soil treated with RDF only (Fig. 17).

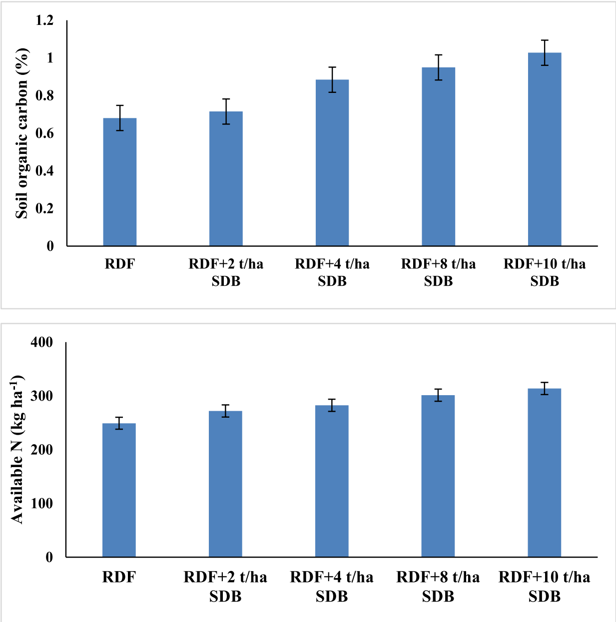


Figure 17. Increase in SOC and available N with application of SDB

High potential of stabilizing carbon and its sequestration

Over the years, many research outputs have highlighted the carbon sequestering capacity of straw derived biochar. Long-term stability of carbon in biochar is the unique feature that is implausible in conventional methods for disposal of straw (Cheng at al., 2008). Biochar has a high non-biodegradable carbon content that can remain in the soil for hundreds to thousands of years (Lehmann et al., 2015). The stability of carbon in biochar varies depending on the feedstock and pyrolysis temperature. Singh et al. 2012 found that the stable carbon content of biochar from slow pyrolysis was 45% at 400ºC to 92% at 550ºC. Yue-feng et al., 2017 reported that the amount of carbon sequestration in biochar applied soil increase by more than 200%, compared to conventional fertilization system. According to laboratory incubation and field observation, carbonizing biomass with biochar application to soil may proactively sequester C from the atmosphere through photosynthesis. In addition, it is believed that application of biochar to soil reduces CH4 and nitrous oxide (N_2O) emissions (Knoblauch., 2011; Yanai, 2007; Liu et., 2011) especially from rice paddy which is a significant source of GHGs (Luo et al., 2011).

Table 4. A summary of recent publications (2016–2020) concerning the extent of reduction in GHGs emissions and subsequent carbon sequestration by application of rice straw derived biochar

Sl. No.	Effect straw derived biochar application	Reference
1.	20% reduction in NH_3 volatilization	Sun *et al.*, 2019a
2.	decreased N_2O emission from paddy fields under flooding irrigation vis-à-vis controlled irrigation	Sun *et al.*, 2019b
3.	CO_2 exchange increased by 2.4% and 31% BC addition increased SOC by 19.1% 33.8 to 43.1% decreased CH_4 emissions	Yang *et al.*, 2019a
4.	CO_2 emissions decreased by 2.22% from paddy fields under water-saving irrigation	Yang *et al.*, 2019b
5.	CH_4 emissions decreased by 28% to 680% from manure incorporated soils	Nguyen *et al.*, 2020
6.	Biochar amendments significantly decreased CH4emissions Soil C increased by 5.75 mg/gand 11.69 mg/g with 14.8 and 29.6 t/ha BC	Sui *et al.*, 2016
7.	The lowest CH_4 emissions was recorded under biochar treatment (4.8–59 mg $C/m^2/hr$) The lowest N_2O emissions was recorded under BC treatment (0.15–0.26 µg $N/m^2/hr$)	Trinh *et al.*, 2017
8.	Low temperature biochar decreased soil redox potential and increased the abundance of methanogenic archaea	Cai *et al.*, 2017

6. Animal feed Block: Rice straw as major ingredients

Why rice straw to be converted in animal feed?

Marginal and small farmers are backbone of the Indian agricultural system and their livelihood and farming system are overly complex in which livestock is a crucial component. The success of livestock health and production depends on proper nutrition which is essential for achieving high and sustained livestock productivity. The livestock nutrition is mainly based on grazing and agricultural by product. Depends on availability, sometimes the dry fodder is replaced by the green fodder to enhances the efficiency of the production system and reduce the dependency on the concentrate feed and reducing the input cost. Farmers generally uses home grown dry fodder for feeding, however, the surplus straw being burn in some of the states as a means of disposal for different reasons. Rice can effectively be converted as preferred animal feed because it is abundant, low in cost and practical source of animal feed.

Why rice straw is not being used a preferred animal feed?

India produces around 300 to 400 million tons of straws/stover annually and on an average only 1/4th of being used as animal feed. In dairy production, straws contributing 45-60% of total feed consumed by them (Kelley and Parthasarathy, 1996; Parthasarathy and Hall 2003; Shrinivasa and Maski, 2017). The reason behind the low use of straw in animal feed is of their low digestibility (less than 50%) and relatively low nutritive value (low protein 4-4.7%), high-lignin, lingo-celluloses complex, high silica, and low nitrogen content. Rice straw contains about 80 percent of substances which are potentially digestible and therefore sources of energy, but actual digestibility by ruminants is only 45 to 50 percent.

How the rice straw can be converted into desired animal feed?

To improve the nutritive value and digestibility of straw it needs physical, chemical and biological treatments/ modifications to convert it to a potential feed source. Some of the important animal feed materials obtained from rice straw after the different treatments and modifications are presented below.

Animal feed from rice straw

Straw pellets

Straws which are left behind by harvesters (combined harvester) in a field can be collected, pulverized, or chopped in small pieces and then pelletized in feed mills with or without any nutritional enrichment, which may enhance their utility as ruminant feeds because, it can be easily stored, transported and used.

Figure 18. Straw pellets as animal feed

This technology has industrial application in the areas where the surplus straw is burned for disposal and causing environmental and health hazards.

Straw-based animal feed block

It is the process of making animal feed blocks of size 20 cm x 20 cm by mixing rice straw with essential nutritional elements. The self-life of the feed blocks is more than one year, very economical to transport to distant places. The rice straw collected from farmers field are passed through chaff cutter machine and straw are made into pieces of about 1to 2-inch size. The other essential ingredients like (rice bran, Molasses, urea, nutritional grain etc.) were added to increase its nutritional quality and chopped rice straw placed in the mixing machine. Generally, composition of feed block varies with the requirements, however, feed block comprises major portion as straw (65%) and other ingredients are rice bran (10-20%), Coconut poonac (up to 10%), molasses ((up to 10%), urea and salt (2%) etc. (Kulathunga et al., 2015). for increasing its nutritional quality and chopped rice straw placed in the mixing machine. The mixture output from the mixing machine is then passes through the feed block making unit which then makes feed blocks of 3.5 kg each.

Figure 19. Animal feed block using rice straw

Densified Complete Feed Block (DCFB)

Densified Complete Feed Block (DCFB) is basically straw-based Densified Total Mixed Ration (DTMR). In this product, roughage (straw and other by product) and concentrate (oil cakes, molasses etc. and other materials contain minerals and vitamins) are mixed in different proportions/ ratio as per requirement and then compacted by hydraulic press to convert in a block with the help of binder. The concentrate mixture is prepared separately and mixed with straw (in a specified ratio) in a specially designed mixer to ensure that these components will adequately mixed. This DCFB has different advantage like cheaper and easier transportation of feed materials, balanced feed/ balance rations to the animals, efficient nutrient delivery, used in emergency like floods, droughts etc.

Urea molasses mineral block (UMMB)

It is a cost-effective approach to maximize the utilization of locally available feed resources and strategic feed supplement for ruminants which can provide constant source of fermentable nitrogen to promote growth of rumen microbes. It significantly increases feed intake, milk production and growth rate. It was prepared by different process called hot process, cold process and modified cold process. Each technique has its own limitation and advantages. Based upon the requirement multi nutrient, vitamins, antibiotics etc. can be incorporated in the block to enrich their nutritional property.

Figure 20. Urea molasses mineral feed block

Alkali treated rice straw

The alkali spray treatment of straws has been reported to improve digestibility and intake. In this chemical process, the straw is sprayed or sprinkled with a dilute solution of NaOH (about 5%) at the rate of 1 litre/kg and the moist straw is immediately fed to animals. It increases degradability and palatability of treated straw (Chaudhry and Miller, 1996; Vadiveloo, 2000). However, this technology is not being used widely, because it may be costly for the poor farmers and not readily available to them. Its application might increase the sodium content in the environment causing environmental hazards.

Spent Straw

Rice straw is commonly used for the mushroom production and the spent straw available after harvesting the mushrooms can be used after sun drying as effective cattle feed.

▶ Economic benefits

i. If the straw is converted into suitable pellets and feed blocks, it will increase the self-life, very economical to transport to distant places, provide balanced feed/ balance rations to the animals, reduce the wastage, can be used in emergency like floods, droughts etc.

ii. Use of feed blocks significantly increases the milk production (10-15 percent) compared with normal feeding practiced (Walli, 2009).

iii. Mushroom production mainly depends on rice straw, and the straw available after harvesting of mushroom can be reuse as animal feed, which reduces the input cost.

▶ Environmental benefits

iv. Converting rice straw into suitable feed materials reduce the production of greenhouse gases that would have been produced by burning of these straws.

v. Feeding of a balanced diet reduces the methane production in rumen by 10-15 percent and that can be easily obtained in case of densified feed blocks (DCFB / DTMR).

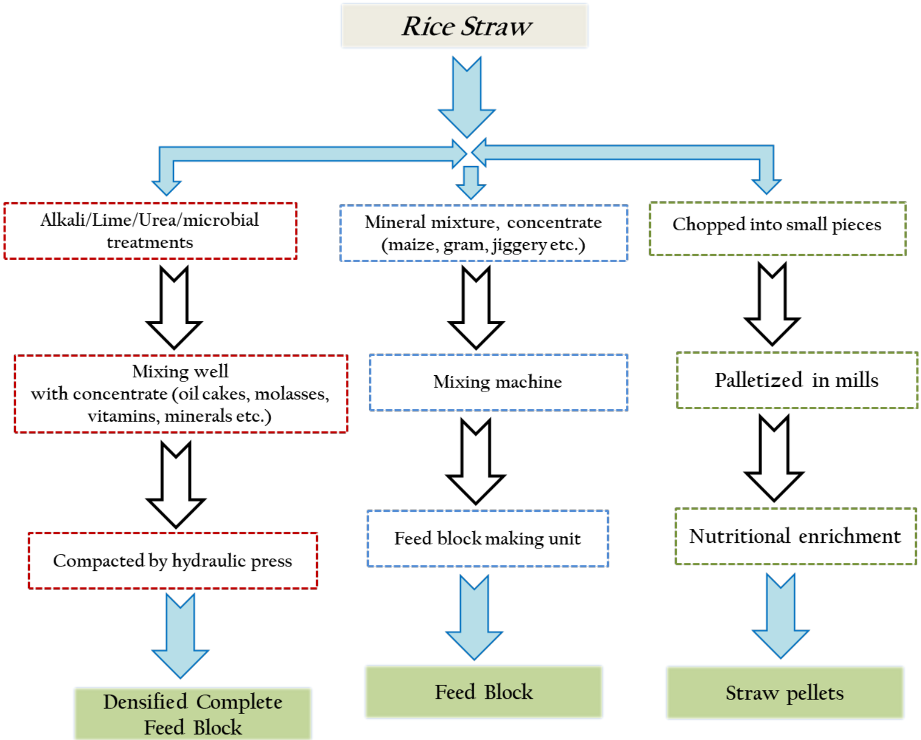


Figure 21. Flow chart for the possible ways to use rice straw as animal feed

▶ Nutritional benefits

vi. The nutritive value of fermented rice-straw showed that it has higher TDN and lower DCP. It also improves conception rate, overall health, rumen fermentation and efficiency of microbial N synthesis as compared to untreated straw (Bakshi and Wadhwa (2017).

7. Rice Straw - Compost

The benefits of compost include providing nutrients as fertilizer to the crop, acting as soil conditioner, increasing the humus or humic acids content of the soil, and introducing beneficial colonies of microbes in the soil. The natural interaction of the soil, plant roots and nutrient / microorganisms of compost improves the soil structure. An improved soil structure will increase the soil water retention ability and control soil erosion. Compost can be used for land and stream reclamation and eco-friendly wetland construction.

What is the Need of rice straw composting?

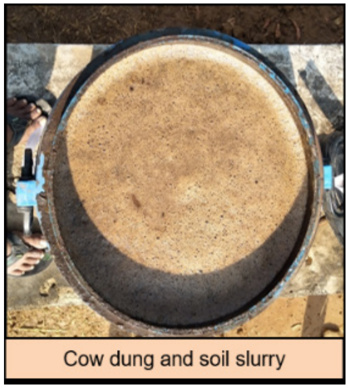
Decomposition of rice straw brings much needed organic manure to the soils that improves soil fertility as well as productivity. Incorporation of rice straw directly to the soil is certainly associated with immobilization of plant nutrients. Ex-situ rice straw composting is a good option in India to tackle the issues like straw-burning and soil health management simultaneously. However, there are few limitations of ex-situ composting. The main bottleneck of rice straw decomposition both in in-situ and ex-situ condition is high C: N ratio of straw and having considerable amount of silica, lignin make it difficult to decompose and takes more time for straw composting. And the second one, the microbes originally from natural sources and with higher lignin decomposing potential are sometimes could not perform in field scale straw decomposition.

Method of ex-situ rice straw composting

For preparation of valuable rice straw compost, we refined the technique of composting with the use of unique microbial consortium (bacteria + fungus) to hasten decomposing process. We make use of large quantity of rice straw biomass, microbial inoculum, cow dung-soil slurry and perforated plastic pipes (4-inch diameter). In this technique, 1 m deep, 3 m wide, and 4 m length earthen base concrete-compost tank was used. The efficient microbial consortium [one bacteria (LB 8 (MN784664)) and one fungus (LF 3 (MK855473)] was selected for rice straw decomposition after evaluation in laboratory and pot culture experiment. For preparing of the consortium, compatibility test of two microorganisms was done, because incompatibility of the co-isolates may also inhibit the growth of each other. After compatibility test, the bacterial and fungal isolate was inoculated into jiggery solution for multiplication for 2 days. The rice straw brought from the field and then spread in the tank in 3 even layers of 30 cm. About 10 tonnes of rice straw was used in one tank. In each layer microbial inoculum was sprayed with the help of a sprinkler and four perforated plastic pipes were placed inside the tank for aeration. Finally, a slurry made from 5 kg of dung and 5 kg soil in 10 liters of water was spread (1-2 cm) over the straw layer for retention of moisture and insulating the heat stress. The moisture content was maintained by adding water regular intervals. The material was turned once after 14 days.

Figure 22. The Pictorial representation of steps of rice straw-compost production at NRRI, Cuttack

The Multiplication of microbial consortium in Jiggery



The Cow dung-soil slurry used to cover the composting material

Figure 23. Maintenance of microbial consortium for rice straw composting

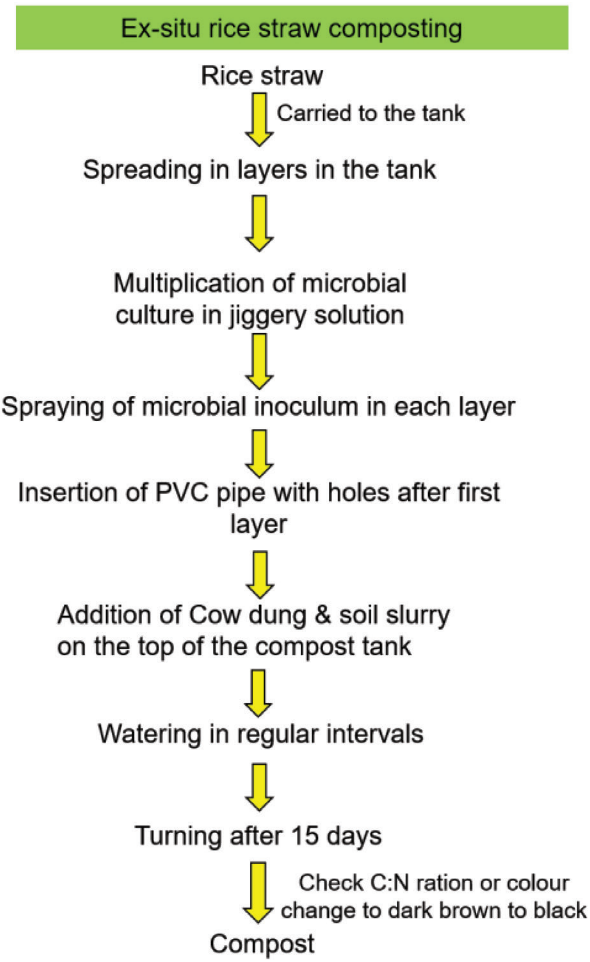


Figure 24. The Flowchart of rice straw-compost production benefits

- *Ex-situ* rice straw composting can be prepared within 40 days with this microbial consortium.
- The consortium has the potential to use in in-situ decomposition of rice straw.
- The C:N ration of rice straw is reduced to ~20.0 after composting.
- This compost can be used at the rate of 5-10 t ha-1; 25% fertilizer cost could be saved.
- Reduces air pollution and increases cost benefit ratio of farmers.

Evaluation of rice straw compost in field condition

Field experiment at NRRI revealed that rice yield could be increased by 36% by addition of rice straw-compost @ 5 t ha-1 little increase of methane and GWP. However GHG intensity (GHGs emission per unit yield) was only 0.59 as compared to 0.57 in case of RDF application (Table ..).

Table 5. Yield and greenhouse gas emission in rice straw compost in compared with RDF

Treatments	Yield (Mg ha^{-1})	CH_4 emission (kg ha^{-1})	N_2O emission (kg ha^{-1})	GWP (Kg CO_2 ha^{-1})	CEE (Kg C ha^{-1})	GHGI (kg CO_2 eq. kg^{-1})
RDF	5.08	92.45	0.975	2848	776.5	0.57
RDF + RSC	5.44	107.95	0.79	3233	882	0.59

Rice straw Composting by Trichoderma

Isolation of Trichoderma and efficacy testing

Different Trichoderma sps. were isolated from tree barks. The isolates were tested for the decomposition capacity of straw and also for use as biocontrol of rice diseases. Two species were short listed for the decomposing of rice straw. Initially we soaked the straw with water and then applied 1% of jiggery solution and then applied Trichoderma formulation having 1x1010 cfu and then covered with polythene. After 7 and 15 days the straw was turned upside down and maintained the moisture by applying water from outside. The straw was decomposed complete after 55-60 days (Figure 24 and 25).

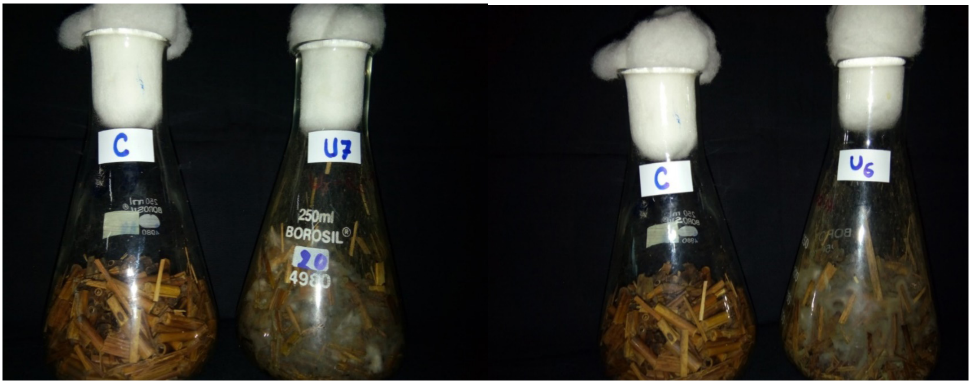


Figure 24. Growth of *Trichoderma* strains (U6 & U7) on paddy straw (C= control)

Control **Treated with U6** **Treated with U7**

Figure 25. Straw decomposition by *Trichoderma* Strains

Both the strains also showed cellulolase and xylanase activity both qualitatively and quantitatively (Figure 26 and 27) which indicates that they are excellent decomposer.

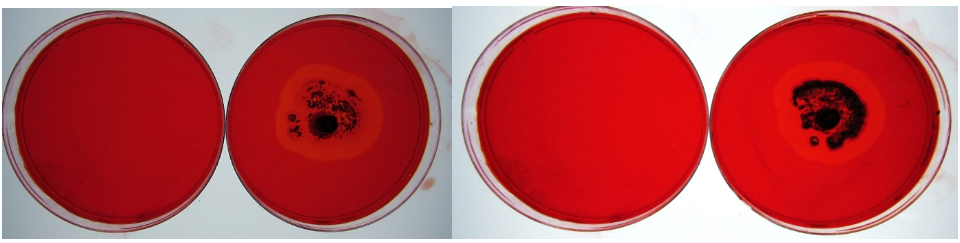


Figure 26. Cellulolytic activity of selected Trichoderma spp.

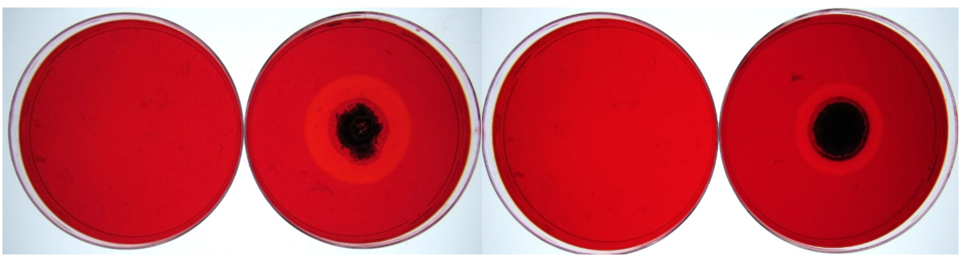


Figure 27. Xylanase activity of selected Trichoderma spp.

So, we can conclude that if we decompose rice straw using Trichoderma species, it not only helps the proper management of rice straw but at the same time adds nutrients in soil and increasing the crop yield.

We tested the effect of Trichoderma assisted compost on rice growth and observed that this compost not only enhances the growth of paddy (Figure 27) but also increased yield and induces resistance to biotic stresses.

Control U6 U7 Control U6 U7

Fig. 27 Growth Promotion activity in seedling and adult plants by using *Trichoderma* decomposed paddy straw (Control; U6 & U7= treated with two different Trichoderma spp.)

8. Futuristic approach of Rice Straw Utilization

Apart from the aforesaid off field end-use options of paddy straw, this waste can be converted to wealth in paper making industries and also in Handicrafts (art & craft) enterprises. Nevertheless, the challenges faced in the existing technology, gaps in value chain management and the disrupted market linkages has obstructed the paddy straw to get its true economic value. This has also prevented the farmers to invest money and time in residue collection and the chain players to invest in these options. With the help of these alternatives, the volume of residues of paddy that can be used is just a mere fraction to the total volume of straw that is generated. These high bulk density straw with high moisture content also demands adequate storage facilities to be the raw material for the off farm end use products. Bringing out a holistic approach of on-farm and off-farm options, straw management can be a productive solution to this burning issue.

With respect to off farm options like paper making industries, paddy straw can be converted to pulp for paper making and then developing some value-added products like paper plate, spoons etc. This can act as a suitable alternative to the use of plastic in day-to-day life. However, selection of a suitable variety of paddy straw is utmost important containing less lignin and more of cellulose and hemicellulose. This process also encompasses several technologies interventions like grinding, bleaching, refining of the straw to get efficient pulp. Further the pulp will undergo calendaring process to get rough paper and on further bleaching, white paper can be achieved. This paper on passing through paper pressing machine (containing different size of die), will produce paper plates, bowls, etc.

Besides this, paddy straw can be used for decorative wall paintings, frames, exhibitions thereby providing another dimension to the use of paddy straw. Research may be carried out to identify suitable adhesives to avoid insect infestation on the paddy straw and also how to extend the shelf life of the decorative items.

9. Options for a way forward

A holistic approach that focuses on biomass management and agricultural policy is needed to address the issue of paddy straw burning. With respect to residue management, the options recently being carried such as subsidies, residue use for power generation etc. involves technical know-how gaps that needs to be looked into.

The management regarding on-farm and off-farm practices related to paddy straw should be documented and also the cost benefit ratio of the above stated practices needs to be evaluated. A clear and concise understanding of the supply chain (from farm gate to end use of the straw) management and associated business models must be carried out. The option of crop diversification of at least 5 % area existing under paddy to locally favourable crops like maize, millets etc. may be a good measure. However, R & D must be carried out with respect to developing efficient package of practices, capacity building of paddy growers as well as providing appropriate market and infrastructure in order to employ crop diversification and minimize straw burning.

AAlternatively the short duration paddy variety may be employed to reduce straw burning as it provides extra time to the farmers for cleaning the paddy residues and wheat sowing. Nonetheless, it requires popularization of these varieties, sufficient seed production, institutional support for package of practices as well as sensitization of the paddy growers. This is because there is less assured guarantee that the extra time they get will motive them to avoid stubble burning as it incurs technological as well as monetary challenges towards straw management.

A consolidated approach of the existing policy and institutional support along with subsidies against residue management, production of clean energy as well as sustainable agricultural practices is necessary to address this issue. Besides, the concerns and the difficulties of the farmers needs to be respected and also there must be a knowledge sharing platform for all the players of the supply chain to bring sustainability to paddy straw residue management.

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