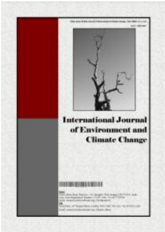

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Alternative Uses of Rice Straw in North-Western Regions of India: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

After sugarcane bagasse and maize straw, rice straw (RS) is globally the third largest form of agricultural residue while, in India, it is the largest form of agricultural residue. In the north-western states of India wheat is taken as a rabi crop and surplus rice straw is a focal issue associated with storage of rice straw, removal of entire straw from the field, and very little time between the cultivation of the crop hence rice straw burning becomes cheap, quick and efficient way for preparing bed for sowing of wheat. Open burning of crop residue kills beneficial soil microflora, degrades soil, and adds to detrimental greenhouse gases such as SO_2, NO_2, CH_4, N_2O, CO, and hydrocarbons and particulate matter in the atmosphere. As a result, burning rice straw is a major source of pollution in the environment. This review looked into rice straw alternatives that were less harmful to the environment, such as RS biochar production, RS as industrial waste adsorbents, RS based bio-methanation, heavy metal amelioration, RS bricks and RS based bioethanol production.

Keywords: Rice straw; biochar; bio-methanation; bio-ethanol; straw burning.

1. INTRODUCTION

Rice, the principal crop of Indian subcontinent covering 43.79 Mha with the 1st advanced estimate of 107.43 Mt [1] is the staple food source for the burgeoning population of the nation. Plethora of farmers, with the support of Governments MSP and monsoon rainfall

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undertake Rice farming as a viable option, which it is. Same goes for farmers of Northern India, but little did they know such an innocuous practice would translate into a catastrophe, which would strangle the Capital of India for a gasp of air. When cereal crops are harvested, we are left with agricultural waste or crop residue as straw. It is a non-edible product, often left in the field after harvesting. Traditionally, paddy straw was seen as a versatile by-product of rice cultivation because it was used in many ways including fodder for livestock and as a building material. However, the increase in productivity and area under cultivation of rice has led to a huge production of rice straw. Moreover, mechanization decreased the animal dependency and hence the feed requirement. So, the most effective way of disposing of the residue is seen as burning of biomass in the paddy field.

It is important to mention that open field burning is a widely practiced method all over the world; however, its intensity varies. The short-term effects of burning seem more desirable than those from soil incorporation due to the immobilization of inorganic nitrogen which occurs in the latter stage and can adversely affect productivity in the short term. Stubble burning, incessant especially in Rice-Wheat cropping zone releases enough pollutants into the air which has turned the situation into an endemic. According to CPCB's Air Quality Management Data, New Delhi (Nehru Nagar) has Air Quality Index (AQI) of 395 on 9^{th} of December, 2021 which fall under category of very poor. Government has stepped up on toes to tackle the menace, but only providing agricultural implements at subsidized cost is not a solution as it increases inflation, also implements experience depreciation and soon wear out and some of the marginal farmers cannot afford these implements even at the subsidized cost. A sustainable, long lasting and holistic solution should also include supporting development of enterprises or even practices which utilize the remnant of RS. Some of the applications of RS would be as industrial waste adsorbent, biochar, bio-methanation, heavy metal amelioration, RS bricks and use in paper and pulp industry.

2. BIOCHAR

Biochar is a byproduct of organic material that has been heated under oxygen-restricted conditions, often at temperatures below 700°C [2]. Biochar is both a planned primary product from the partial pyrolysis of biomass and a byproduct of biomass pyrolysis (or gasification) to make biofuels [2]. Regardless of the temperature and residence time during pyrolysis, Rice Straw biochar is often alkaline. Alkaline biochar can be added to soil to improve fertility, neutralise acidity, and sequester carbon in acidic soils. According to Dong et al. [3], rice straw biochar improved nitrogen retention and rice production in a soggy paddy field. In North China, applying at least 2 t/ha of rice straw biochar to a cold, wet paddy field resulted in a considerable decrease in CH4 emissions, global warming potential, and greenhouse gas intensity, according to Cui et al. [4]. 's research. It seems like adding rice straw biochar to a chilly, soggy paddy crop would be beneficial [5]. The size of the pores in biochar when it is buried in soil is crucial because it will allow soil bacteria to colonise the spaces that are available while preventing grazing predators of bigger sizes from following [6]. Many soils treated with biochar support enhanced plant growth due to improved physical and chemical properties [2]

Although the majority of literature findings showed beneficial aspects of biochar amendments, there are some limitations. First of all, biochar has an inhibitory effect on soil aging and intermittent addition of fresh biomass might be required for optimal nutrient cycling and soil-water environment in a soil. For instance, in a study carried out by Anyanwu et al. (2018), it was proven that biochar aged in soil has negative effects on growth of earthworms and/or fungi. In addition, the aged biochar also led to reduction in underground root biomass of *Oryza sativa* and *Solanum lycopersicum*. It has proven to exhibit reduction in soil thermal diffusivity to reflect low thermal diffusivity of biochar (Zhao et al., 2016). Contrary to popular findings, the beneficial effects of biochar are also proven to be soil specific. Thus, biochar amendment may not necessarily play a positive role for all types of soils (Zhu et al., 2015).

3. INDUSTRIAL WASTE ADSORBENT

3.1 Organic Dyes

Some agricultural wastes serve a dual use as inexpensive materials and potent absorbents for some organic contaminants, such as basic dyes, which are acutely poisonous and carcinogenic [7]. Dyes are synthetic, aromatic compounds that are common in the textile, food, plastics, cosmetics, and tannery industries. They are released into the environment as wastewater from these sectors [8]. Every year, the textile, food, plastics, cosmetics, and tannery sectors release around 2% of the dyes they create as effluents [9]. They are more resistant to chemical, photochemical, or microbiological deterioration because of their stable chemical structures [10]. The majority of these colours may have harmful impacts on aquatic ecosystems and human health as a result of partial treatment techniques used before disposal [11].

In an experiment conducted by [12] it was demonstrated how adsorbing efficacy of RS can be increased.

As shown in Fig. 1, once the surface property of the adsorbent was changed from hydrophilic to hydrophobic, the modification of rice straw with a cationic surfactant improved the sorption effectiveness for Yellow20 dye from 36.44 percent of the dye being removed before modification to 96.01 percent [12].

3.2 Phenol

Phenol pollution is a significant environmental problem. Phenolic compounds are a typical wastewater pollutant. Phenol is very soluble in water, and even at concentrations as low as 5 g/L, its presence in water supplies can be detected as an unpleasant taste and odour [13]. Phenols are a class of organic compounds that share structural similarities with more widely used insecticides and herbicides, including their resistance to biodegradation [14]. They are extensively employed in the industrial manufacturing of a wide range of resins, including phenolic resins, which are utilised as building materials for automobiles and appliances, epoxy resins and adhesives, and polyamides for a variety of uses [15].

Fig. 2 displays the phenol removal effectiveness of several selected adsorbents with increasing adsorbent dosage. The phenol adsorption capacity for both particle sizes was found to rise in the following order: thermally treated (ash)>physically treated>raw rice straw. Among all types of adsorbents investigated, ash of >1 mm rice straw particles demonstrated the best phenol removal efficiency of 84.07 percent for 2.5 g adsorbent dosage at equilibrium. Raw rice straw undergoes thermal treatment (ashing), which destroys the organic matrix and increases the surface area for phenol adsorption.

4. BIO-METHANATION

According to Trivedi et al. [16], the anaerobic digestion technology is the most effective method for managing biomass resources to produce energy and bio-fertilizer in terms of energy output/input ratio. Actual field experimental data from a demonstration scale bio-methanation facility at Fazilka, Punjab, are used in the bio-methanation of paddy straw given by Trivedi et al. [16]. From the entire region of Fazilka, Punjab, paddy straw was delivered in bales and stored there. Additionally, the paddy straw is manually dispersed across the conveyer belt's

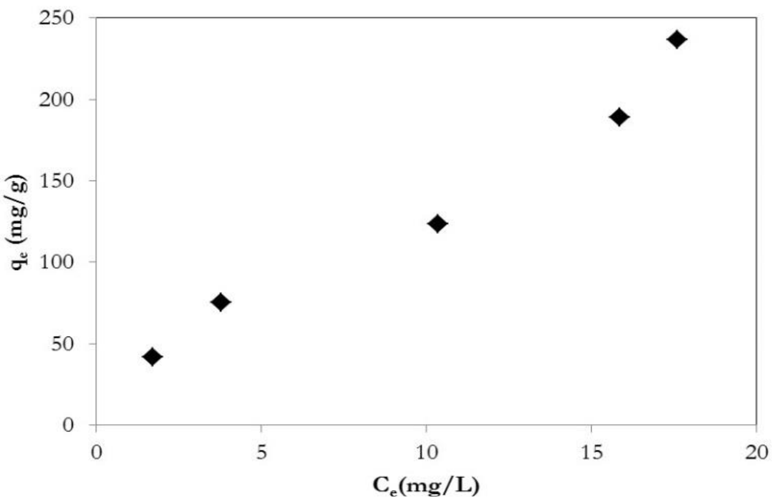

Fig. 1. Adsorption isotherm of the dye sorption by the organo-rice straw with increasing contact time

Source: [12]

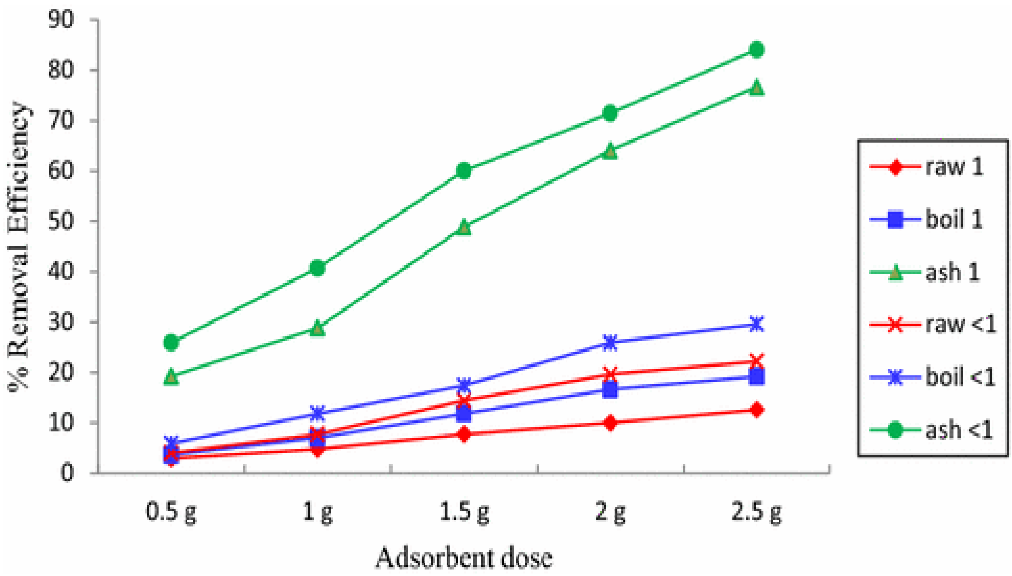

Fig. 2. Percentage removal of phenol with different adsorbent dosage for different adsorbents; Contact time- 24 hours

breadth before being fed into the pulverizer, where it will be reduced in size to a range of 3-5 mm. Calculations are started at the point of paddy straw pretreatment for the creation of biogas for the energy balance. It is clear from Tables 1 and 2 that converting paddy straw to

Table 1. Energy analysis of paddy straw-based biogas power production

Unit	Power Consumption (kWh/h)	Operating time (hr)	Total power consumption
Energy Input			
Paddy straw pre-treatment (pulverization)	94.00	10.00	940.00
Substrate feeding unit	23.00	10.00	230.00
H_2S scrubbing unit	13.75	10.00	137.50
Bio-fertilizer unit	13.75	10.00	137.50
Total energy input (kWh)		**1,445**	
Energy output (kWh)		**8,000**	
Net energy gain (kWh)		**6,555**	
Output/Input		**5.5**	

Source: Trivedi et al. [16]

Table 2. Cost–benefit analysis of paddy straw-based biogas power production

	Rs/10 tonne paddy straw	Rate (Rs/unit)
Output		
Electricity (8,000 kWh)	60,000	7.5 /kWh
Bio-fertilizer (5.0t)	35,000	7.0/kg
Input		
Paddy straw cost	-15,000	1,500/tonne
Paddy straw pretreatment	-7,050	
Substrate feeding unit	-1,725	
H_2S Scrubbing unit	-1,031	
Bio-fertilizer unit	-1,031	
Net benefit	**69,163**	
Output/Input	**3.6**	

Source: Trivedi et al. [16]

biogas through pulverisation results in a net energy gain of 655 kWh/tonne and a cost savings of 6,916/tonne of paddy straw. It was shown that using rice straw to produce biogas can result in a positive net energy balance of between 70% and 80% [16].

5. HEAVY METAL AMELIORATION

Because heavy metals are poisonous and seriously harm both humans and animals, their presence in the aquatic environment is a major cause for concern. Aqueous effluents from numerous industrial operations often contain hazardous metal pollutants. The World Health Organization (WHO) lists aluminium, chromium, manganese, iron, cobalt, nickel, copper, zinc, cadmium, mercury, and lead as the metals of greatest immediate concern. Particularly harmful and highly toxic are cadmium and its derivatives. Many health disorders, including the major killer diseases like heart disease, cancer, and diabetes, are exacerbated by cadmium poisoning. Cadmium is more hazardous than either lead or mercury and concentrates in the kidney, liver, and several other organs.

5.1 Nickel and Cadmium

Sayed et al. [17] investigated the possibility of using rice straw as an adsorbent for Nickel and Cadmium, and they discovered that it is an effective adsorbent for the two metal ions, particularly for Cadmium. The maximum adsorption capacities for Ni and Cd were 35.08 and 144.19 mg/g, respectively. The dosage of the adsorbent, the beginning concentration of metal ions, and the initial pH all had a significant impact on the sorption capacity. The experimental data had strong correlation coefficients and was well-fit to the Langmuir and Freundlich equations. The analysis of the thermodynamic parameters revealed that the adsorption process was exothermic in nature and spontaneously thermodynamic under natural conditions.

5.2 Chromium

Opening the cellulose molecular chain's link, adding new functional groups, and altering cellulose's intrinsic properties all change the structure of rice straw fibre. To replicate an adsorption research of marine heavy metal Cr effluent, high adsorption capacity cellulose is developed. Leiming et al. [18] evaluated the removal process and the effectiveness of modified rice straw for adsorbing Cr in simulated waste water by static adsorption experiments.

The removal efficiency of Cr and the yield of the modified straw generally increase and subsequently decrease with an increase in the dosage of straw. The removal rate of Cr increases from 85.5 percent to 92.5 percent when the straw dosage is increased from 5 g to 7 g; at 6.5 g, the removal rate and duct yield peak; as the dosage is increased further, the removal rate declines dramatically and the yield is lowered [18].

5.3 Lead

Heavy metal lead is used in many industries, yet it can have a negative influence on both the environment and people's health. Recent studies have examined the viability of removing heavy metals from wastewater using various low-cost materials. One of the most dangerous heavy metals for both the environment and human health is lead [19]. The immune system as well as the neurological system are both seriously harmed. Battery production, electroplating, etrochemical reactions, printing pigments, and fuels are a few industrial operations that use Pb.

The change in the removal efficiency of Pb versus the final pH of solutions containing rice straw is shown in Fig. 3 of a study by Amer et al. [20]. Additionally, it displays how pH changes the amount of Pb removed from liquids without rice straw (control). The pH of a solution had a big impact on how much metal was removed by rice straw. The adsorption of Pb using rice straw was only about 12-45 percent at low pH levels, in the range of 2-3.5. As seen in Fig. 3, at higher pH (3.5 to 6), the percentage of Pb removal rose significantly, reaching almost 90%.

6. RICE STRAW – BRICKS

Since straws can be used as a lightweight concrete mix to create an eco-architecture building, study on straw bale walls, also known as rice straw walls, is required [21].

Countries including China, the United States, and Australia are responsible for the development of this straw wall. The building wall is constructed by spinning rice straws into hay that is roughly 30

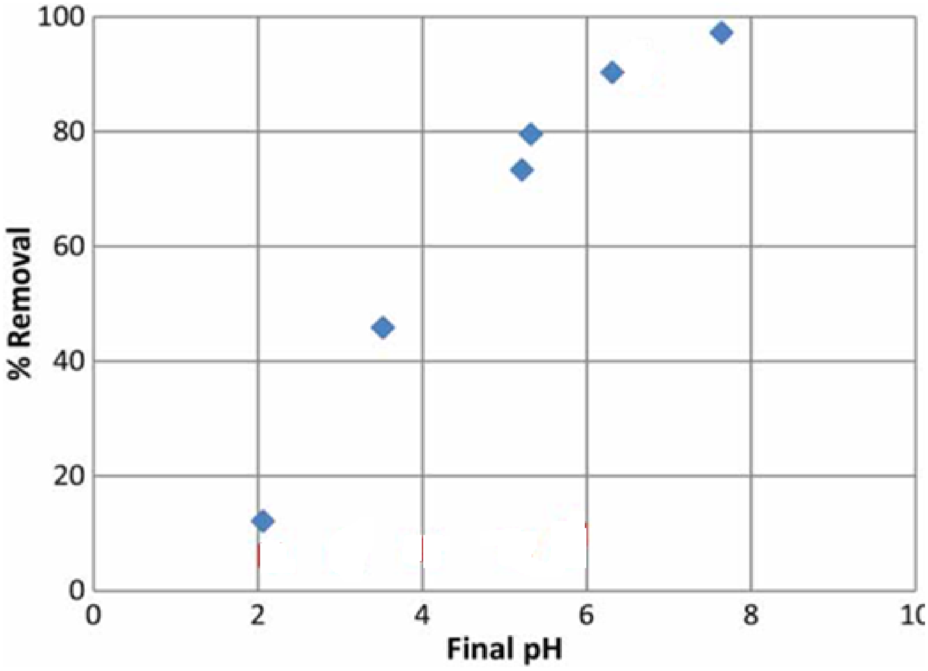

Fig. 3. Final pH of the solution vs. the percentage removal of Pb (II) (dose 2 g/l, contact Time: 4 h, C_0: 40 mg/l)

Source: Amer et al. [20]

to 60 cm long. Then, to strengthen it, the hays are put into a wall frame and coated with wire mesh. After that, mortar is used to plaster it. The workload will also be smaller as a result of the structure's less weight, making it safer and better suited for living in earthquake-prone areas. Clay brick is less environmentally favourable when used in construction, especially wall-shaped brick [21].

When a specimen is loaded with a specific amount of compressive force generated by a compressing machine, the amount of load per area unit that causes the specimen to shatter is known as the concrete bricks' compressive strength. Compressive strength for non-structural lightweight concrete ranges from 0.35 to 6.9 MPa, and its specific gravity is less than 1900 kg/m3.

The maximum compressive strength of the straw variant no. 7 (from Table 3) with a volume of 0.00175 m3 was 1.92 MPa, whereas the compressive strength of concrete bricks without straws was 5.896 MPa [21]. The variation was perfect for compressive strength value. The price was acceptable as non-structural lightweight concrete [22].

7. BIOETHANOL

Rice straw has the potential to produce 205 billion litres of bioethanol annually, or nearly 5% of global consumption. It comes from a single biomass source in the greatest quantity. Cellulose (32-47%), hemicelluloses (19-27%), lignin (5-24%), and ashes (18.8%) are the main components of rice straw. Rice straw contains the following carbohydrates: glucose (41-43.4%), xylose (14.8–20.2%), arabinose (2.7–4.5%), mannose (1.8%), and galactose (0.4%) [23].

The heterogeneous complex structure of rice straw contains entangled lignin and hemicellulose as well as rigid cellulose fibre because of its crystal structure. Pretreatment by physical and/or chemical means is required in the bioconversion of lignocellulose to ethanol in order to weaken the structure and make it easier for biocatalysts such cellulase, xylanase, and ligninase to produce fermentable sugars. Because they may disrupt the ester bonds between lignin, hemicellulose, and cellulose, alkali treatments using NaOH, KOH, CaOH, and Na2CO3 are particularly more effective than other chemical processes. As a result, lignin and some of the hemicelluloses are simultaneously eliminated [24].

Table 3. Variations of straw hay bale

No Variation	Volume of straw hays (m^3)	Size of hay straw length*width*height (mm)	Quantity
1	0.000000	0	3
2	0.000625	250*50*50	3
3	0.000750	300*50*50	3
4	0.000875	350*50*50	3
5	0.001250	250*50*100	3
6	0.001500	300*50*100	3
7	0.001750	350*50*100	3
8	0.001875	250*50*150	3
9	0.002250	300*50*150	3
10	0.002625	350*50*150	3

Source: Sumarni and Wijanarko, [21]

To effectively produce ethanol from lignocellulosic biomass, such as rice straw, which contains a lot of xylose, it is important to use xylose-fermenting microorganisms. The parental strain of Mucor sp. is an ethanol-producing fungus that can ferment N-acetyl glucosamine as well as glucose, xylose, and other monosaccharides [25].

Below the consecutive methods and findings of Takano and Hoshino [26] have been mentioned to briefly summarize their findings on production of ethanol from Rice straw.

One of the ideal biomasses that makes an excellent feedstock for ethanol production is rice straw, which has been studied using a variety of treatments and fermenting microorganisms. Table 4 compares various Simultaneous Saccharification Fungi (SSFs) employing rice straws that have been pretreated under circumstances similar to those of this investigation. The production of ethanol was highly correlated with all conditions. For each report, different enzyme reagents were employed, and these reagents successfully hydrolyzed the substrates. To tackle that problem, we offered efficient selection and optimization techniques that produced effective SSF at low reagent doses. As can be shown in Table 4, pretreating rice straw with alkali increased ethanol production and produced significantly greater yields than acid treatment. These yields in particular were considerably higher than those of acid treatment procedures. Alkali treatment's ability to weaken fiber's crystal structure and cause crystallisation led to advantageous hydrolysis and subsequent fermentation. Because the tuning of the enzyme mixture had a significant impact on the hydrolysis of the straw, our study's results showed the highest ethanol production and yield of these reports. Additionally, it makes sense that the M. circinelloides strain utilised in this study was able to produce fermentable sugar by secreting a small amount of cellulases in addition to converting glucose and xylose to ethanol. According to the findings of these research, productivity on SSF with Mucor fungi was fairly high.

The pretreatment method of alkali (NaOH) with heating produced material with a high sugar content (30.6 g/L) and effectively removed lignin from raw rice straw. A selection of necessary enzymatic activities and suitable reagents for the processed rice straw might be derived through multivariate analysis. Based on the analysis, three types of desired reagents were chosen from a total of 15 types of commercial enzyme reagents. For the most efficient synthesis of fermentable sugar from the alkali-treated straw, DOE and RSM proposed an ideal ratio of an enzyme cocktail made up of the three reagents. The enzyme cocktail created by these statistical techniques increased hydrolysis efficiency from low efficiencies with each reagent alone to 83.3 percent at 2 g-protein/L. With a 90 percent fermenting efficiency of fermentable sugar basis, SSF of the alkali-treated straw utilising an M. circinelloides and the cocktail produced a lot of ethanol.

Table 4. Comparison of SSF of several pre-treated rice straws by various strains

Treatment	**Cellulase**	**Strain**	**Maximum ethanol concentration (g/L)**	**Productivity (g/L/h)**	**Temperature (°C)**	**pH**	**References**
H2SO4	BTLX	*Saccharomyces cerevisiae*	6.83	0.284	38	5.0	Karimi et al. [27]
		Mucor indicus	7.79	0.649	38	5.5	
		Rhizopus oryzae	9.2	0.383	38	5.5	
NH_3	Celluclast 1.5 L Accellerase 1500 Novozyme 188 Xylanase	*S. cerevisiae*	12.7	0.250	38	4.8	Ko et al. [28]
H_2SO_4 and NaOH	Crude cellulase from *Aspergillus* and *Trichoderma*	*Kluveromyces* sp.	23.2	0.386	42	4.8	Narra et al. [29]
NaOH	Accellerase 1000	*S. cerevisiae and Scheffersomy-ces stipitis*	28.6	0.777	38	5.0	Suriyachai et al. [30]
NaOH	Celluclast 1.5 L Novozyme 188 Pectinase	*Pichia kudriavzevii*	24.3	1.01	40	4.0	Oberoi et al. [31]
NaOH	Cellulase T Cellulase Onozuka 3S Pectinase	*M. circinelloides*	30.6	0.850	28	5.5	Takano and Hoshino [26]

8. CONCLUSION

Rice straw use optimization is not solely the duty of farmers; the government should enact laws and regulations to prevent stubble burning. There must be public awareness about RS management, as well as mandatory RS management training for farmers. Farmers can also benefit financially from the use of RS. RS can be used for production of biochar which will help in alleviating soil health and also increase carbon sequestration while putting the RS to good use. Using RS as industrial waste adsorbent is also as option for both harmful organic dyes and heavy metals present in industrial effluents. Lightweight bricks using concrete and RS should also be promoted as they inflict least damage in earthquake prone areas being lightweight and also since RS bricks are cheaper to make, they can also be used for making cheap bricks for makeshift homes. Also, RS can be used as a fuel for a variety of reasons, including reducing greenhouse and other harmful gases. In this approach, the ecosystem can be safeguarded against future pollution crises. RS should be able to be moved from the field to the factory with minimal effort, else all efforts would be in vain. Private players must form up units locally and employ their new and old technologies for greater farming practice. RS has already been mentioned as a possible substitute for nonrenewable energy fuel using processes of bio-methanation and formation of bioethanol. These actions help to preserve the environment for future generations. In the future, small power thermal plants may be able to run on stubble instead of coal. Subsidies should be implemented by the government to encourage the use of these biofuels. Local governments in India and other countries can be more responsible when it comes to enacting particular regulations. In Bangladesh and Indonesia, some NGOs (Non-Governmental Organizations) have begun to provide microfinance for small-scale renewable energy projects.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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