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Optimizing the Use of Rice Straw for Sustainable Packaging Materials (Molded Products, Paper and Board) Production


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Abstract:

Rice is a staple food crop widely grown across India during the Kharif crop season. After grain extraction, rice straw is produced in substantial quantities and is traditionally used in applications such as mushroom cultivation, composting, and biogas production. One way to utilize rice straw is as a raw material for production of pulp, by chemically, mechanically, or chemi mechanically separating cellulose fibers from the straw. However, utilizing rice straw for pulp and paper production presents challenges in conventional pulp and paper-making processes. Virgin pulp made from these cellulose fibers has been used to create biodegradable food containers, medical products, and industrial packaging. The alternate technologies for processing rice straw shows strong potential for further commercialization. However, the costs of producing and selling rice straw pulp, molded products, paper, and paperboard vary.

The packaging market for various grades of paper and board is on high growth and demand is fast growing particularly in sectors such as food and beverages, where virgin pulp is only required. Shortage of fibrous raw materials remains a persistent issue for the Indian pulp and paper industry. This communication highlights CPPRI's efforts in optimizing the use of rice straw to develop sustainable packaging materials for different end uses and thus support high value addition to rice straw.

Keywords: *Rice Straw, Molded Products, Packaging material, Fibre Fractionation*

Introduction

Rice is one of the most popular foods on the planet. Nearly 510 million metric tons of milled rice was produced in the last harvesting year (2022-2023) worldwide, providing employment to hundreds of millions of families, particularly in Asia and Africa's rural areas.

However, despite its popularity and economic significance, rice cultivation faces sustainability challenges: To prepare the fields for the next harvest, more than 50% of the surplus rice straw residue must be burned. The results are high concentrations of air pollution, which are associated with critical health issues, damage to soil fertility and contribution to the greenhouse effect. With time, however, more and more innovative solutions have emerged to address this problem [1,2].

Rice straw is used for papermaking in the countries of southern and eastern Asia (i.e. China, India, and Sri Lanka) and in Egypt. However, rice straw is costly to collect and store. Despite these drawbacks, it is a favored fiber source in the wood short countries, due to its ready availability [2].

The demand of paper and board packaging material has grown very fast in all over all world with CAGR around 12-15% and even higher in some sectors. To meet the growing demand for pulp, paper and paper board, it is essential to utilize lignocellulosic biomass, which is available from agricultural, industrial, and forest waste. The agro residues like rice straw utilization in India, where the availability of agro residues is significantly higher compared to other nations, its use may help in mitigating the shortage of fibre. Despite some drawbacks, agro-based lignocellulosic materials offer several advantages, such as [1-3]:

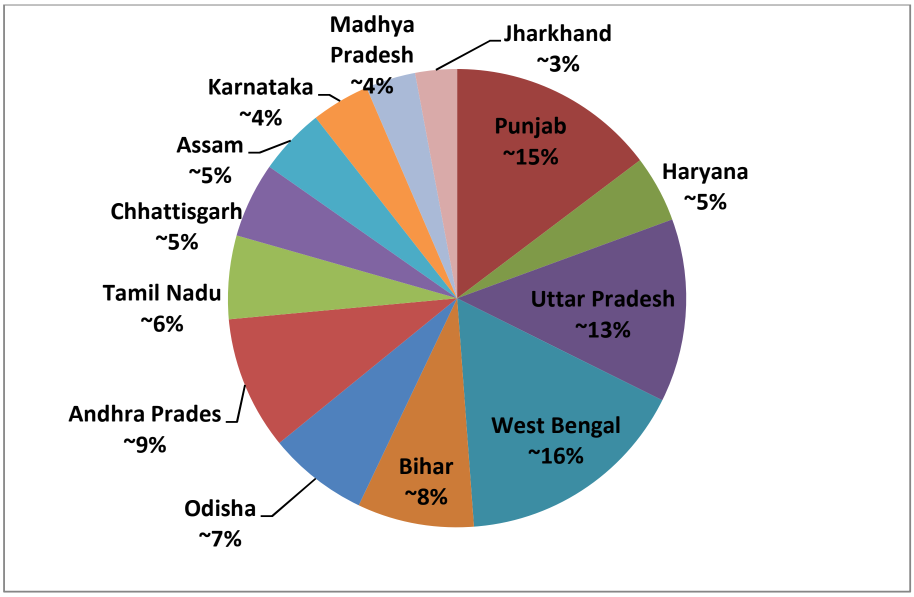
1. They are renewable annually.
2. They require fewer chemicals for pulping.
3. Expensive chemical recovery systems are unnecessary.
4. Cheap chemicals like lime can be used for straw and similar materials to produce semi-chemical pulp.

5. Small mills can be established with less capital investment.
6. Shorter gestation periods are needed for setting up these units.
7. The process and equipment are simpler.
8. Energy consumption is lower.

There is also a need for research and development to address the challenges associated with rice straw utilization and to create methods for producing specific products from straw as an alternative to wood. Rice straw can be used in production of strawboard and "B" grade wrapping paper. Rice straw production is directly proportional to rice cultivation, and the management of this byproduct is crucial for sustainable agricultural practices. However, many states face challenges in dealing with the excess rice straw, which, if properly utilized, can serve as a valuable resource for various industries, including packaging, bioenergy, and composting.

Rice straw production varies significantly across states in India (Fig. 1) due to differences in cultivation practices, climate, and the area under rice cultivation.

In Punjab, rice straw production is ~23-25 million tons per year. Punjab has a high yield per hectare, contributing significantly to rice straw production, which often leads to stubble burning due to short turnaround times for the next crop. In Haryana, rice straw production is ~7-8 million tons per year. Like Punjab, Haryana produces a large amount of rice straw, and the stubble management remains a challenge. In Uttar Pradesh, rice straw production is ~20-22 million tons per year. The state is the second-largest producer of rice and hence contributes significantly to rice straw production. In West Bengal, rice straw production is ~26-28 million tons per year.West Bengal is the largest rice-producing state in India, with rice straw production being one of the highest in the country. In Bihar, rice straw production is ~12-14 million tons per year. Bihar is one of the important rice-producing states in eastern India, with moderate rice straw production. In Odisha rice straw production is ~10-12 million tons per year. Odisha has substantial rice cultivation areas, contributing significantly to rice straw production. In Andhra Pradesh, rice straw production is ~15-16 million tons per year with large irrigation networks. In Tamil Nadu, rice straw production is ~8-10 million tons per year. Rice is a major crop in Tamil Nadu. In Chhattisgarh, rice straw production is ~8-9 million tons per year. It is known as the rice bowl of central India, Chhattisgarh is a major contributor to rice straw. In Assam, rice straw production is ~7-8 million tons per year. Assam is a key producer in the northeastern region, with significant rice straw production. In Karnataka, rice straw production is ~6-7 million tons per year. With favorable conditions for rice cultivation, Karnataka has a moderate rice straw production. In Madhya Pradesh, rice straw production is ~5-6 million tons per year. In Jharkhand rice straw production is ~4-5 million tons per year [1-5].



Issues Related with Rice Straw

Fibre morphology of rice straw indicates that parenchyma cells are high in rice straw as compared to wheat straw .The chemical pulp of rice straw with kappa number 12-13 requires less chemical as compared to wheat straw and bagasse but the yield of rice straw chemical pulp is low. When rice straw is subjected to chemical pulping, most of the parenchymatous cells are converted into fines and also responsible for drainage problem. Another big challenge with rice straw is the presence of silica, which is major problem in chemical recovery and make rice straw unsuitable for conventional chemical pulp production. The silica content is more than 5% in general irrespective of location as depicted in Table 1 [2, 8-9].

Agricultural residue pulps, such as rice straw, contain a significant amount of fines, and their initial freeness before refining is very low. Due to this low initial freeness, these pulps cannot undergo extensive refining. The high fines content in these pulps also impairs the runnability of the stock on the paper machine. The fibre fractionation of pulp may help in segregation of fines with useful fibre, thus making it suitable for better strength paper than the whole pulp [4].

Rice straw pulps consist of approximately 35% fines that pass through a 200 B&M fraction, which are mainly non-fibrous (parenchymatous) tissue. These whole pulps lose freeness quickly during refining. For example, freeness decreases from 350 to 190 ml CSF after just 500 revolutions in the PFI mill. Interestingly, the fibers in the refined whole pulp appear largely unchanged compared to unrefined fibers. This suggests that the non-fibrous components absorb most of the refining energy, preventing effective development of the fibers themselves.

Due to fragility of rice straw fibre and presence of silica in high quantity, it is advised to use semi-chemical or chemi-thermomechanical pulping (CTMP) for production of different packaging grade pulps, where bleaching is mild or not required. The pulp thus produced is reinforced with long fibre pulp and sizing chemicals in order to increase the strengrth potential of pulp for different high strength packaging papers/boards. The semi-chemical or CTMP pulping of rice straw followed by mild refining is another way of utilizing rice straw, which helps in lowering in effluent load and also nullifies the silica problem.

In the present communication, the viable options of utilizing rice straw for various grades of packaging and molded products are explored. By applying alternate techniques it is possible to utilize the rice straw for production of various value added packaging materials.

EXPERIMENTAL

Characterization of Rice Straw

Cellulosic fiber characterization involved determination of its proximate chemical composition. Proximate chemical composition included the evaluation of following parameters: ash (TAPPI T 244 cm-99); cold and hot water solubility (TAPPI T 207 cm-99); 0.1 N NaOH solubility (TAPPI T 212 om-02); alcohol benzene solubility (TAPPI T 204 cm-97); holocellulose (TAPPI T 249 cm-00); and acid insoluble lignin (TAPPI T 222 om-02). A certain quantity of rice straw was converted into 100 g of dust having mesh size 40 using the laboratory dust making machine.

Pulping Experiments

Pulping experiment was carried out in laboratory series digester for pretreatment, followed by refining of pretreated mass in sprout Walden disc refiner. At the end of refining the disintegrated refined mass was thoroughly washed and pressed to obtain air dried pulp. After thorough washing, the air dried pulp was screened in laboratory screen using mesh of 0.25 mm slot width to remove the rejects. Unbleached pulp was characterized for essential parameters following standard TAPPI methods.

Fibre Fractionation

The Bauer McNett classifier (model with 4 classifier chambers) was used for fiber fractionation of semichemical refined pulp of rice straw according to TAPPI T 233 cm-06. In fiber fractionation of rice straw pulp different mesh like 50, 100 and 200 classifier screens were used.

RESULTS AND DISCUSSION

Chemical Composition of Rice Straw

Table 1 depicts the chemical composition of rice straw (state wise variation in chemical composition). The holocellulose in rice straw is average 55% which is lower than other paper making raw materials.

Table 1: Proximate chemical analysis of rice straw from different regions

S. No.	Parameters,%	Chhattisgarh	Punjab	West Bengal	Uttar Pradesh
1.	Ash	17.28	14.17	16.47	14.20
2.	Silica	10.29	7.0	9.5	6.95
3.	Acid insoluble lignin	16.51	15.02	13.96	13.55
4.	Holocellulose	53.11	56.42	58.62	55.96
5.	Pentosan	18.51	20.14	22.31	18.2
6.	Hot water solubility	19.29	21.53	16.78	19.58
7.	Cold water solubility	11.84	12.91	8.58	10.33
8.	1/10 NaOH solubility	45.07	44.08	45.06	45.46
9.	Extractives	5.39	7.23	4.13	4.25
10.	α-Cellulose	36.92	37.65	38.57	36.58
11.	β-Cellulose	11.53	10.34	14.92	14.33
12.	γ-Cellulose	4.65	8.43	5.13	5.04

Semi-Chemical Pulping

Conditions of semi-chemical pulping and the results are given in table 2.

Table 2: Semi-chemical pulping of rice straw

Cooking chemical, NaOH%	2.5
Solid liquid ratio	1:10
Cooking temperature, ºC	130
Time at maximum temperature, hours	3.8
Pulp yield, %	63.0
Pulp freeness, ml CSF	250

Fibre Classification of Rice Straw Pulp

Improved fiber quality can be achieved by separating fibers based on length and diameter. Baur-McNett classifiers can produce pulp with more consistent and desirable properties. Pulp processed with Baur-McNett classifiers can lead to paper with improved strength, tear resistance, and printability. These classifiers can help optimize the pulping process by reducing waste and improving overall yield.

The results of fibre fractionation on pulp properties are given in tables 3 and 4.

Production of Paperboard/Fibre Board of Semi-chemical Pulp of Rice straw

After fibre classification, the low potential pulp can be used as kraft

Table 3: Baur McNett classification of rice straw

Particular	No of cells per gm/10^6	Cell coarseness	No of fines (<0.2mm)	Weight of fines, gm	Average fibre length, mm	Maxm length of fibre, mm
Whole pulp	42.10	0.061	62.24	17.57	0.30	0.64
+50 fraction	23.61	0.089	29.86	4.31	0.48	0.78

Table 4: Effect of fractionation on strength properties of rice straw pulp samples

S. No		Rice straw	Whole pulp	+50 Fraction of rice straw pulp			
1	PFI, rev	0	500	0	500	1000	2000
2	Freeness (CSF), ml	425	200	580	482	310	200
3	Apparent density, g/cm^3	0.92	0.98	0.79	0.84	0.91	0.96
4	Burst index, kPam^2/g	1.82	2.96	1.70	2.10	3.11	3.46
5	Tear index, MNm^2/g	5.14	4.87	6.01	7.98	7.90	6.89
6	Tensile, Nm/g	25.1	40.6	26.3	42.1	48.1	50.4
7	Stretch, %	3.0	3.86	2.8	3.9	4.2	4.6
8	Fold, km log	0.78	1.2	0.61	1.27	1.40	1.68

pulp. Kraft Pulp is used to produce different grades of kraft paper for various paper products like packaging materials, corrugated board, and kraft paper.

Kraft paper is widely used for packaging products like flour, sugar, dried fruits, and vegetables.

Kraft paper is available in three grades [6-7]:

1. **Grade A:** Known in the paper industry as virgin kraft, it is made from 100% unbleached sulfate pulp or a mixture of wood and bamboo pulp.
2. **Grade B:** This grade, known as semi-virgin or agricultural residue kraft paper, is made from bagasse, rice/wheat straw, grass, jute, or a combination of these materials mixed with sulfate pulp.
3. **Grade C:** Made from 100% waste paper or a blend of waste paper and agricultural waste, this is referred to as non-virgin kraft paper in the paper trade and industry.

   The primary difference between paper and paperboard is their grammage, with paperboard typically having a grammage greater than 250 gsm. Paperboard generally consists of multiple layers and is thicker than paper.

   Inexpensive, low-grade waste papers like newspapers can be used for the internal layers of paperboards, providing a cost-effective alternative. However, for food-grade applications, only virgin-grade paper is permitted, meaning multi-ply boards containing recycled newspaper or other papers are unsuitable for direct food contact. Multi-ply boards consist of two or more layers compacted into a single paperboard and are used for making rigid boxes, as well as milk and juice cartons. Ventilated paperboard boxes are often used for the transportation and storage of fruits and vegetables.

4. **Fibre board [5]**

   Transportation of fruits, vegetables and the perishable items, a wooden box of 20 kg Fruit/ vegetable capacity contains 3.5 kg of wood. Replacement of wooden boxes with straw fibre board boxes with straw fibre board boxes would not only save wood for better utilization but would also save the forest wealth. Properties of the fibre board obtained from straw are given in the table. Strength properties of the board conform to the laid down specifications. Straw fibre boards have modulus of rupture comparable to wood fibre board. Straw fibre boards have modulus of rupture comparable to wood fibre board. A portion of surplus straw could be utilized for producing number of products in addition to paper and board. Part of the surplus quantity of the straw could be utilized for different kinds of products in addition of paper and paperboard. Composite boards prepared from semi chemical rice straw containing different proportion of pulp made from rags jute paper, jute fibres are suitable for board manufacturing (Tables 5 and 6).

   The results indicate that MOR of untreated fibreboard is comparable to laid down standards, though the water absorption is higher than desirable but the same could be drastically brought down by heat or oil tempering treatment or by the addition of additives during manufacture which is also a commercial practice.

Table 5: Properties of straw boards

Basis weight, gsm	870
Breaking length, m	2840
Density yield, %	0.43
Bulk, cm^3/g	2.32

Table 6: Properties of the fiberboards

Thickness of the board, mm	3.2	-	-
Density, g/cm^3	1.0	-	-
MOR, kg/cm^2	370	523	584
Tensile strength, kg/cm^2	270	315	371
Water absorption 24h, %	150	49	430
Thickness swelling 24h, %	130	60	310

Use of CMP Pulp of Rice Straw for molded Products

Rice straw molded pulp products are new products created from leftover rice straws, allowing the straws to be reused as agricultural waste without needing to be burned. These straw molded pulp products can be used for a variety of purposes, such as packaging fruits, vegetables, dry food and even holding hot meals for up to 48 hours. Rice straw molded pulp products are made from the agricultural byproduct of rice production. This straw is sourced from rice-growing regions around the world, like China, India and Indonesia. Traditionally, rice straw was considered a waste material and often burned, causing air pollution and environmental degradation. However, with the advent of sustainable practices, this agricultural residue has now been repurposed into eco-friendly packaging.

By repurposing this abundant and often underutilized resource, rice straw molded pulp products contribute to the local agricultural economies in these regions in several ways:

Firstly, by creating a demand for rice straw molded pulp products, farmers can generate additional income from rice farming. Secondly, the production of rice straw molded pulp products often involves collaboration with local farmers and communities, which fosters economic development by creating employment opportunities, particularly during harvest season. This holistic approach not only benefits the environment but also creates positive social impacts that extend beyond the scope of packaging production.

Versatile uses

The versatility of rice straw molded pulp products has made them useful across numerous industries. For fruits, vegetables, and pastry (fresh or frozen), they offer excellent packaging solutions, and they can hold hot meals for up to 48 hours. Rice straw molded pulp products provide protection, stability, and ventilation, ensuring safe transportation and storage of goods. Furthermore, their natural appearance and texture can enhance the visual appeal of products, adding an organic touch to the overall presentation.

Sustainable value

One of the key advantages of rice straw molded pulp products is their sustainable value. As a byproduct of rice farming, their use helps reduce agricultural waste and prevents the burning of this waste, which is extremely harmful for the environment. The rice straw molded pulp products are made from natural materials – and at the end of their life, when placed in a composter, they become nutrient-rich compost. They can also be disposed of along with paper waste in the appropriate bin.

Moulded pulp packaging is created by molding a mixture of water and fiber into various shapes through pressing and drying. This packaging typically consists of 96% water and 4% fiber, along with waterproofing agents like wax and resins. The results of CTMP of rice straw are shown in Tables 7 and 8 for molded pulp production.

Table 7: Properties of rice straw pretreated and refined pulp

S. No.	Parameters	Expt. 1	Expt. 2
1	Raw materials		
2	Alkali charge (NaOH)	2 %	3 %
4	Bath Ratio	1:6	1:6
5	Temperature, ^{0}C	95	
6	Time, minute	30, 90	
	After steaming in bombs at 95^{0}C these materials are taken for refining in disc refiner at 20 and 10 tou.		
7	Unscreened yield, %	80.0	82.5
8	Screening yield, %	74.2	76.0
9	Brightness, ISO %	25	26
10	CSF, ml	340	322

Table 8: The physical strength properties of rice straw CTMP pulp

200 gsm hand sheets of CTMP unbleached pulp samples were prepared through laboratory sheet former for physical strength properties					
Physical strength properties	**gsm**	**Burst Index, k.Pa.m^2/g**	**Tensile index, N.m/g**	**Bulk, cc/g**	**Tear index, mN.m^2/g**
Unbleached pulp sheet (NaOH 2%)	200	0.9	11.8	2.19	2.78
Unbleached pulp sheet (NaOH 3%)	200	1.0	15.0	1.96	2.90

Production of Chemi-mechanical Pulp by Urea Pulping and Blending with Gunny waste Pulp for Packaging Board

Compared with traditional packaging materials such as plastic, rice straw molded pulp products offer an outstanding sustainable packaging solution. Due to their renewable source, diverse applications, and compostable nature, they provide businesses with an opportunity to align their packaging practices with their sustainability goals. By embracing rice straw molded pulp products, growers, retailers, bakeries and even restaurants can contribute to a greener future while delivering their products in an eco-friendly manner.

The tables 9 and 10 shown results indicate that unbleachable grade chemi-mechanical pulp, with satisfactory strength properties for wrapping and packaging paper can easily be prepared by using urea as pulping chemical.

High tear strength paper

Tables 9 and10 indicate the beating characteristics and the physical strength properties of the used gunny bags pulp produced by cooking with 5% sodium hydroxide followed by refining in a disc refining in a disc refiner. It also shows the strength properties of the blends of rice straw chemi-mechanical pulp produced with 8% urea followed by refining, (freeness value 330 ml CSF) and the gunny bag pulp after beating to a freeness value of 250 ml CSF, blended in different proportions. It is evident form table 10 that there was improvement in the tearing strength as the proportion of long fiber pulp was increased (8).

Comparison of urea pulp with soda pulp

A comparison is made between the two pulping procedure by using 8% urea and 4% sodium hydroxide on rice straw. Table 8 shows the results of delignification, pulp yield, pulp quality, effluent quality (BOD and COD) and the cost of cooking chemical in each pulping procedure.

Results indicate that urea spent liquor showed less BOD and COD values than the soda spent liquor and requires very less effort in treatment and after treatment, effluent can be send to agricultural field for irrigation purpose because of the advantage of the nitrogen present in the spent liquor.

TABLE 9: Comparison of urea and soda pulping [8]

S. No	Particulars	Pulping process	
		NaOH	NH_2CONH_2
1	Cooking chemical on raw material, %	4.0	8.0
2	Pulp yield, %	67.9	68.2
3	K-Number	29.8	35.6
4	Spent liquor analysis	8.6	8.2
	a. pH	8.6	8.2
	b. Lignin removed, % on total lignin present in raw material	71.7	55.4
5	Strength properties at freeness of 200 ml CSF		
	a. Tensile, Nm/g	44.5	35.6
	b. Tear, mNm^2/g	3.80	4.9
	c. Burst, kPm^2/g	2.30	2.16
6	Effluent analysis:		
	a. COD, kg/ton pulp	453	417.5
	b. BOD, kg/ton pulp	147	124.0

Table 10: Results of strength properties of urea pulping and blending with Gunny pulp [8]

	PFI, rev	Freeness, CSF ml	Drainage time, min	Apparent density g/cm^3	Burst index, kPm^3/g	Tensile index, Nm/g	Stretch, %	Fold kohler molin log	Tear index, mNm^2/g
Used Gunny pulp	0	400	5.27	0.56	2.80	50.0	2.1	1.87	12.0
	500	255	8.16	0.57	3.90	64.0	2.4	1.92	9.3
	1000	210	9.66	0.58	4.10	66.5	2.4	1.98	8.65
	2000	165	13.32	0.61	4.80	76.0	2.6	2.10	8.30
Pulp blend of: 10% used gunny + 90% urea pulp		330	20.3	0.56	1.30	28.0	1.5	0.84	5.50
20% used gunny + 80% urea pulp		320	19.7	0.57	1.65	31.0	2.0	1.04	5.85
30% used gunny + 70% urea pulp		295	22.4	0.57	1.97	33.0	2.2	1.23	6.90

**Pulp blends produced from urea pulp (300 ml CSF) and used gunny pulp (255 ml CSF)*

Conclusions:

The rice straw availability is in abundance. It is available at much lower price than other paper making fibres. The judicious use of rice straw in a proper manner can convert rice straw into value added products for production of various packaging grade paper, board and molded products.

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