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Potential Use of Agricultural Residues in Chemical-Free Handmade Paper Manufacturing

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ABSTRACT

Solid waste is one of the most significant issue of civil society. The demand for paper has been growing since its conception since it can be used for a variety of purposes. It is expected to increase by about 16.7% in 2023 compared to 408 million tonnes in 2021, with China, the United States, North America, and India having the biggest demand. Paper demand can be estimated at around 529 million tons per year by 2025. The tremendous market for paper products promotes 14% of deforestation, which disturbs the ecosystem and causes habitat loss, soil erosion, flooding, and a rise in greenhouse gas emissions. Therefore, a handmade method of producing papers using agricultural waste as the raw material is found to be an alternative method of meeting demand while reducing environmental impacts. This is because the paper produced is chemical-free, economical, environmentally friendly, and has a significant impact on the growth and preservation of forests. Chemical-free handmade papers were manufactured from ready pulp using raw materials only. These papers were sun-dried and then ironed for straightening. Moisture content (%), kappa number, ash content (%), GSM(g/m^2), Tensile strength (KN/m), Burst index ($KPam^2/g$), lignin content. Thickness(mm) and Absorbency (g/m^2) were analyzed of the handmade papers. It was found that papers from sugarcane bagasse fibers are useful for soft usage like tracing papers, handmade drawing sheets etc. while the papers from rice straw are heavy and suitable for heavy and rough usage. This research work is eco-friendly and it used agricultural waste as raw material which signifies sustainability of environment and hence better future.

Keywords: Handmade, Sustainability, Eco-friendly, Waste, Environment.

INTRODUCTION

The demand for paper has been growing since the beginning since it can be used for a variety of purposes. It is expected to increase by about 16.7% in 2023 compared to 408 million tonnes in 2021 (Ian, 2022), with China, the United States, North America, and India having the biggest demand. Paper demand can be estimated at around 529 million tons per year by 2025(Bhodiwal *et al.,* 2022). According to Weinberg (2000), 14% of deforestation occurs to meet the huge demand for paper products, which disturbs the ecosystem and causes habitat loss, soil erosion, flooding, and an increase in greenhouse gas emissions. Because the paper produced is environmentally friendly and has a significant impact on forest growth and preservation, a handmade method of producing papers using agricultural waste as the raw material has been found as an alternative method to meet demand while reducing environmental impacts. Additionally, compared to machine-made paper, the handmade technique uses significantly less electricity and could result in lower manufacturing costs (Smith and Johnson, 2017). At this critical moment, the global paper sector must simultaneously meet growing demand while reducing its negative effects on the environment. Paper is an essential component of our everyday lives and is used extensively in writing, printing, packing, and photography, among other applications. Every day, almost 300 million tonnes of paper are produced worldwide (Alam *et al.,* 2004). The production of conventional paper is mostly dependent on raw materials derived from wood, which greatly increases carbon emissions, habitat destruction, and deforestation.

Wood is an organic material that is haSrd, fibrous, and contains lignin and cellulose fibers (Riki *et al.,* 2019). According to King *et al.,* 2000, wood is the secondary xylem found in tree stems. Deforestation results from the billions of trees that are taken down to make the paper. Global warming is caused by the significant CO_2 emissions that result from this deforestation. However, the process of manufacturing paper from wood involves a number of dangerous chemicals, such as hydrogen peroxide, chlorine dioxide, and chlorine, which have an adverse effect on both the environment and human health. As a result, focus has turned to sustainable, alternative feedstocks like agricultural waste. Because of their high cellulose content, economic viability, abundance, and sustainability advantages, rice straw and sugarcane bagasse are particularly promising among them. Researchers hunt for an acceptable extra resource, such as agricultural leftovers, for paper manufacture in order to address all of these issues. This introduction explores these materials potential as raw materials for papermaking, highlighting the technological, financial, and environmental consequences. About 3.7% of the world's paper production comes from the Indian paper sector. With an installed capacity of over 22 million tonnes and an average capacity utilization of 80%, the nation now has over 600 paper mills (Ahmed, 2019). India is reportedly one of the world's fastest growing paper markets, with a Compound Annual Growth Rate (CAGR) of 8% from 2011 to 2016 compared to 1% for its international counterparts.Eighty-eight percent of the nation's raw materials are RCF, twenty-three percent are wood-based fiber, and nine percent are agro-based fiber. 38% of the paper produced in India is waste paper, 8% is news print, and 53% is packaging grade (Damm, 2018). The two biggest and most lucrative sectors of the Indian paper industry are writing/printing paper and paperboard. One of the most prevalent agricultural wastes in India is rice straw. Making paper from rice straw provides a sustainable substitute for pulp made from wood. In areas where rice is a prominent crop, rice straw is created as a byproduct of rice farming. Asia (China, India, Indonesia, Bangladesh, Vietnam, Thailand, and others), together with a few regions of Europe and the Americas, are the world's leading producers of rice. An estimated 738 million metric tonnes of rice were produced worldwide in 2021 (FAO, 2023). Depending on average straw-to-rice ratios, 3,000–4,000 million tonnes of rice straw might be produced worldwide each year. The top producers of rice straw are China, India, and Indonesia. Every year, China alone generates between 200 and 250 million tonnes of rice straw. Paper usage and demand have increased dramatically in parallel with population growth. Around 402 million tonnes of pulp, paper, and paperboard are needed annually worldwide; this need has only increased in the last two years (Kulkarni, 2013). By 2021, it's estimated that 521 million tonnes of paper would be needed annually (Pulppapernews, 2015). Paper consumption rose from 316 to 351 Mt between 1999 and 2005, and it was predicted to reach 500 Mt in 2025, representing an annual increment of 1.6% (Gracía *et al.,* 2008; Parkash, 2012; FFI, 2013). Sugarcane (Saccarhum officinarum) bagasse is a byproduct of the sugar industry that is produced in vast quantities. Bagasse, a fibrous by-product of processing sugarcane, has long been acknowledged as an important resource for paper mills. Brazil's paper mills rely heavily on sugarcane bagasse as a feedstock, and efforts have been made to improve pulping techniques in order to boost productivity. Sugarcane bagasse is used on a local and industrial scale in Brazil's paper industry. Like India and Brazil, Indonesia has experimented with using bagasse as a raw material to make paper, mostly for lower-quality paper goods and packaging.

Approximately 26–30 million hectares are used for sugarcane cultivation worldwide, and an estimated 1.9 billion metric tonnes of sugarcane were produced in 2023 (FAO, 2023). Every year, India produces over 300 million tonnes of sugarcane, which yields 40–50 million tonnes of bagasse. Bagasse, the fibrous waste left behind after sugar is extracted from sugarcane, typically yields 280 kg per tonne of sugarcane (Sun J. X. *et al.,* 2004). Nevertheless, sugarcane bagasse is still being utilised sparingly and mostly as fuel for sugar mills. The manufacturing of pulp depends on these polymers. Currently, a sizable amount of this bagasse is utilized to make paper, mostly as chemical or semi-chemical pulp. India has advanced significantly in the production of paper from sugarcane bagasse. A variety of paper products, including newsprint, writing, and printing sheets, are made from bagasse. Several mills in Maharashtra and Uttar Pradesh are prominent examples of the many mills in India that have switched to using bagasse as a raw material.(Y. S. Antaresti *et al*., 2002). Bagasse is thought to provide between 20 and 25 percent of India's paper production, or about two to three million tonnes of paper per year (Charlesand Shuichi, 2003).An estimated 17 million tonnes of paper were produced annually in India as of 2020. Over 5 million tonnes, or a sizable amount, come from non-wood sources, including as agricultural wastes like bagasse and rice straw.As environmental concerns and sustainable practices gain traction, it is anticipated that the usage of rice straw and sugarcane bagasse for paper manufacture would rise in the years to come. The competitiveness of these non-wood fibers in the production of paper will be increased by ongoing research and development, especially in the areas of pulp quality improvement and processing cost reduction.

Fiber, the Essential Paper Unit

Cellulose is all that makes up paper. The thin felted substance created from boiled vegetable fiber on flat, porous moulds is known as real paper. Fiber-more especially, cellulosic fiber-is the fundamental component of paper, suggest Chauhan *et al.,* (2009). In pulp and papermaking, fiber is usually a slender, elongated or tubular, incredibly tiny plant cell. In its natural form, its length can vary from approximately 1 mm up to over 120 mm, although its diameter is extremely tiny and insignificant measuring less than 0.1 mm (100 μm). Standard fibers used in papermaking usually have an L/D ratio of between around 50 and 200:1(Parham, 1983).

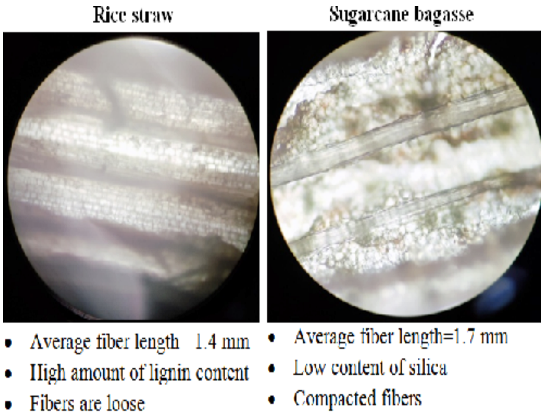


Fig. 1. Microscopic LS section of fibers of agricultural residues (rice straw and sugarcane bagasse)

Chemical composition of agriculture residues

A key determinant of rice straw and sugarcane bagasse's viability as raw materials for papermaking is their chemical composition. The distinct compositions of the two agricultural leftovers have an impact on the procedures used to produce pulp and paper. An outline of the chemical composition of sugarcane bagasse and rice straw is provided below:

Table 1: Chemical composition of agricultural residues (Fahmy *et al.,*1974; Sun and Cheng, 2002; Hemmasi *et al.,* 2011; Sluiter *et al.,* 2012; Pandita *et al.,* 2015)

Agricultural residues	Composition (%)							
	Cellulose	Hemi cellulose	Lignin	Silica	Extractives	Ash content	Proteins	Fats & oils
Rice straw	45-55	25-33	18-23	10-20	5-10	12-15	3-4	<1
Sugarcane bagasse	35-37	25-35	10-12	-	2-5	5-6	3-4	<1

MATERIAL AND METHODOLOGY

Handmade Paper Production from Rice Straw and Sugarcane Bagasse

Reusing agricultural waste to produce valuable paper products is made possible by the environmentally friendly technique of handmade paper production from agricultural wastes such as rice straw and sugarcane bagasse. To turn rice straw into high-quality paper pulp, specific treatment techniques are needed because of its lignocellulosic nature. From raw material preparation to final paper manufacturing, there are multiple steps in the lab-scale handmade paper process. A detailed explanation on making handmade paper from rice straw and sugarcane bagasse is below:

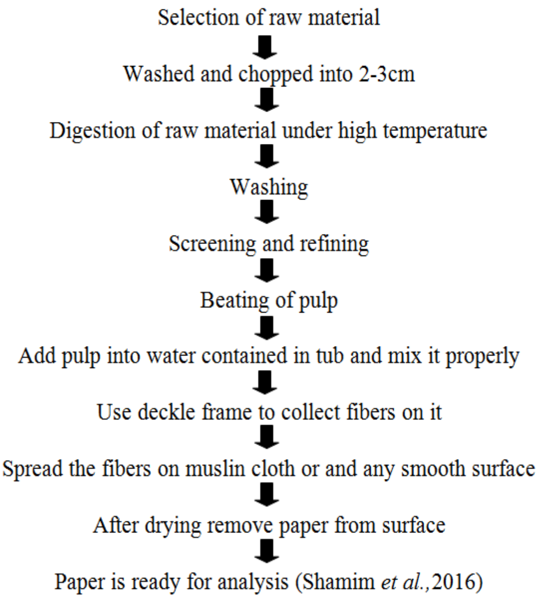


Fig. 2 Flow chart of steps for handmade paper production from agricultural residues

Steps for Handmade Paper Production from Rice Straw and Sugarcane Bagasse

Collection & Preparation of Raw Materials

- Village Madina, District Rohtak, Haryana, India, is where both samples were collected.
- **Rice Straw:** Collected rice straw after harvest and allowed samples to air dry. To make pulping easier, cut the straw into little pieces that are about 1-2 inches long and washed 4-5times with tap water.
- Sugarcane Bagasse: In a similar manner, bagasse was usually collected and chopped in fibrous form and allowed to dry in the sun and washed with tap water.
- Depithing, chopping, and debarking were done to remove non-cellulosic material, following the process of Gullichsen *et al.,* 2000).

Digestion of raw materials (Pulping)

Of the three pulping methods-mechanical, biological, and chemical-the mechanical method was chosen since it is friendly to the environment and doesn't involve the use of chemicals. The process of digestion separated the cellulose fiber needed to make paper from lignin and other wood constituents. An organic material called lignin holds the cells, fibers, and vessels that comprise up wood together. After cellulose, it is the second most prevalent natural polymer in the world. However, it was removed because it quickly breaks down and discolors the paper. Fibers were also mechanically separated from one another during digestion.

Washing and Refining the Pulp

The pulp is usually contaminated with contaminants such as tiny fibers and lignin residues following the mechanical grinding process.

- **Pulp washing:** To create pure pulp, the pulp was cleaned with tap water after it has been produced. This removed contaminants such undigested material, solubilized lignin, raw chips, and dust (Kumari and Rai, 2022). This was usually accomplished by continuously washing and draining the pulp in a large bucket or sink.
- **Refining:** To improve fiber separation and to increase their flexibility for the paper-making process, pulp was made to undergo additional refinement after washing. This step was done by hand and blender.
- To ensure that the final pulp is smooth and appropriate for papermaking, screening was done to remove any big or unrefined particles from the pulp.
- **Pulp beating:** To help the individual cellulose fibers stick to one another in the paper web, they were slightly beaten down at this stage because they were still quite stiff and hollow. The fibers will be frayed and flattened at the end of the operation, ready to be bonded into a sheet of paper.

Forming the Paper Sheet

- Forming the paper sheet by hand was the next stage after the pulp was prepared.
- Getting the deckle and mould ready: Used a wooden frame with a rectangular border (deckle) and a mesh (mould). Throughout the forming process, the deckle made sure that the paper should kept its consistent thickness and shape.

Papermaking Process

- The pulp was poured into a huge water-filled tub. To enable the fibers to float freely, the water-to-pulp ratio is roughly 5:1.
- Shaking the frame from side to side, carefully removed the mould and deckle from the water after submerging them in the pulp mixture. The pulp fibers were more uniformly distributed throughout the mesh as a result of this process.
- After the water was allowed to drain off, a small layer of moist pulp remained on the mesh.
- Removed the deckle when the pulp had been dispersed evenly.

Pressing and Drying the Paper

To eliminate extra moisture and harden the paper, the sheet was pressed and dried after it had been manufactured.

- **Pressing:** Two layers of absorbent muslin cloth are sandwiched between the wet sheet. The cloth gave the paper a smooth surface which helped in water absorption. The fibers were compacted and extra moisture was removed using a press (or physical pressure).
- **Drying:** The pressed paper was allowed to air dry at normal pressure and temperature.
- Depending on the paper's thickness, this required several hours. As an alternative, we can use a heat source to dry the paper, but be careful not to harm the fibers.

Finishing Touch

Depending on its intended application, the paper was further polished and finished once it had dried.

- **Cutting:** Cut the paper to the appropriate dimensions.
- **Smoothing:** To obtain the appropriate texture and finish, the surface was rubbed with a smooth stone or another object or pressed again.
- **Optional Coating:** A thin layer of starch or clay, for example, might be applied if a glossy or particular finish was needed (Ekhuemelo *et al.,* 2012).

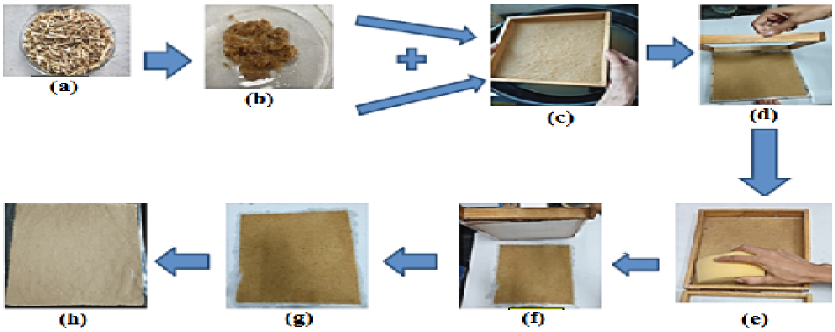


Fig. 3. Process of handmade paper production from rice straw (a) Raw material (rice straw) (b) pulp (c) fibers collected on deckle frame (d) pulp spread on muslin cloth (e) extra moisture absorbed by sponge (f) removed deckle frame (g) paper kept for drying under room temperature (h) final handmade paper.

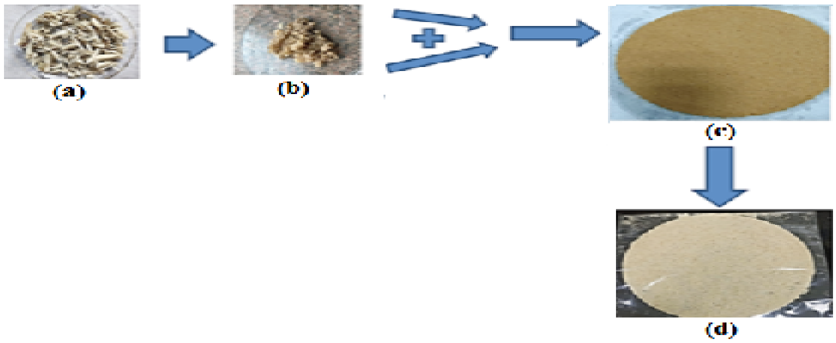


Fig. 4. Process of handmade paper production from sugarcane bagasse (a) raw material (sugarcane bagasse) (b) pulp (c) paper kept for drying at room temperature (d) final handmade paper

Experiments for chemical analysis

Moisture content

Until their weight remained constant, the samples were maintained at 105°C in an air-forced drying oven. The percentage of moisture content was then determined in the manner described below:

MC(%) = {(WW-DW)/WW} *100

Where,
WW = Wet weight of sample and plate (g)
DW = Dry weight of the plate and sample (Ramdhonee and Jeetah, 2017)

ASH content

Crucibles containing 3–5 g of oven dried material were heated to 550°C for two hours in a muffle furnace. The following was the method by which the Ash Content (AC) was calculated:

AC (%) = 100 – VSC (%)

Where,
VSC (%) = (Loss in weight /Net dry weight) × 100 (Ramdhonee and Jeetah, 2017)

Lignin Content and Kappa number

To 0.25 g of crushed material, 150 mL of distilled water, 17 mL of sulphuric acid, and 17 mL of potassium permanganate were added. The mixture was stirred for around 10 min before 3.7 millilitres of potassium iodide were added. The mixture was titrated against sodium thiosulphate until a pale hue was achieved after adding two drops of starch indicator. This procedure was carried out repeatedly until a colourless solution was achieved. The calculation of the Lignin Content and Kappa number was done as follows:

P-No = 75–v
K–No = (P–No)×(f/w)
%L = (K-No)×0.155
Where:
P-No = permanganate number
K-No = Kappa number
v=titre value (ml)
f=correction factor (50%)
w=Weight of raw sample mixed with distilled water (g)
L = Lignin Content (Ramdhonee and Jeetah, 2017)

Experiments for mechanical analysis

GSM

After being divided into equal pieces, the paper samples were weighed using an analytical scale. The formula given below was used to find the basis weights in grams per square meter (GSM):

GSM = weight of paper/area of paper

The unit of measure for paper texture is GSM (grams per square meter). Ordinary office paper weight 80 g/m^2, fine paper weighs 100 to 120 g/m^2, and paperboard weighs 250 g/m^2 or more (Jiménez and López,1993).

Tensile strength

The Tappi standard (T 494 om-01) was followed while conducting the tensile strength test. Tensile strength in N/m divided by grammage is known as the tensile index. The tensile index, which represents the paper's elasticity, is determined by exerting a tensile force along to the paper's plane that is sufficient to cause failure or rupture (Chauhan *et al.,* 2009). Tensile index is calculated in Nm/g (TAPPI, 1988).

Burst Index

The burst indices is the product of a paper's bursting power and its grammage in its conditioned form.

Burst index (k P am^2/g) = burst strength/ basis weight (Chauhan *et al.,* 2009).

Thickness

Applying an empty micrometer and expressing the results in mm or "microns," a thickness of paper, the board, including tissue may be determined on just one ply or many plies (Kishore *et al.,* 2001)

Absorbency

Paper samples were cut into uniform pieces, submerged in water for 60 secs, and then taken out and placed between blotter papers to determine their water absorbency (Cobb value). The standard Cobb Test TAPPI T 432 for sized boards was followed in this process. The weight difference between the wet and dry samples was then used to calculate the water absorbency, which was as follows:

Cobb value = (W2 – W1) × 100 m^2

*W in grams

RESULT AND DISCUSSION

Handmade Papers

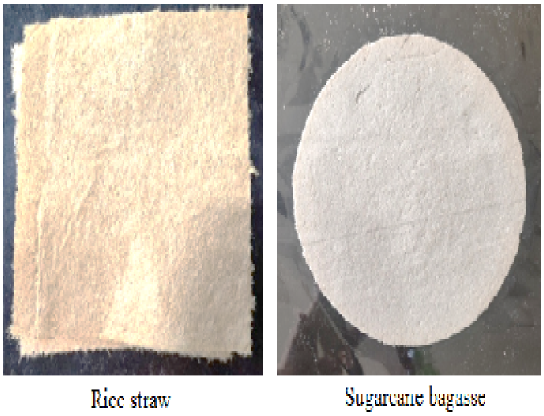


Fig. 5. Handmade papers from two different agricultural residues

Chemical Analysis

Age, variety, environment, location, and other factors can all affect the chemical composition (Manilal and Soni, 2011). Rice straw had a moisture level of 40.2%, which is marginally higher than the 45.2% the amount that Kumar *et al.,* 2013 reported. Bagasse fiber's moisture percentage of 39.8% was much lower than fresh bagasse fibers' 50% moisture content (Anwar, 2010). Climate, plant species, soil type, country of origin, and agricultural techniques can all affect moisture content, which can lead to variations. As a result, variations in moisture content affect a number of mechanical strength characteristics. Therefore, in accordance with ISO 187, all sheets were prepared according to Kumar *et al.,* 2013.

Ash is the remaining non-flammable material following burning or cremation. Because sugarcane bagasse had more fibers than rice straw, it had a higher ash level (Chandra and Dolan, 1998). According to ISO 302:2004, the kappa number, which ranges from 1 to 100, roughly represents the effectiveness of the amount of lignin remaining after pulp has been delignified. This figure is a crucial indicator of pulping completeness and aids in calculating how much chemical will be needed for bleaching. Rice straw's (96.8) and sugarcane bagasse's (79.2) high Kappa numbers suggested that they could be further delignified through bleaching processes. Although the lignin percentage of bagasse fiber was lower (10.53%) than that of rice straw fiber (12.8%), it was still far lower than the 15% value that Srinivasan and Sathiya (2010) observed. In general, less energy is needed to pulp the fiber using mechanical or chemical methods when there is less lignin present (Paper Task Force, 1996).

Table 2: The initial chemical compositions of agricultural residues

Agricultural residues	Moisture content(%)	Ash content(%)	Lignin content(%)	Kappa number
Rice straw	40.2	15	12.8	96.8
Sugarcane bagasse	39.8	20	10.53	79.2

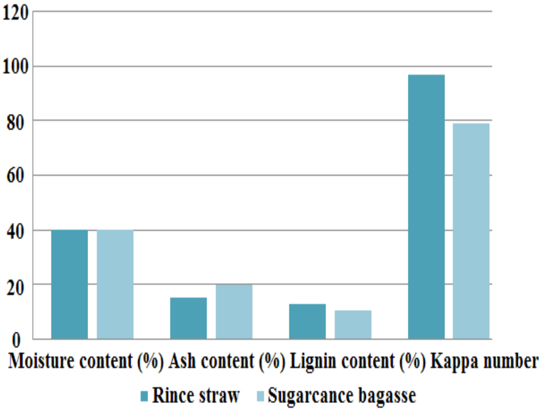


Fig. 6. The initial chemical compositions of agricultural residues

Mechanical Strength Analysis

GSM

Grammage affects the physical properties of paper, which is why it is used. Boards and other non-print papers are appropriate for higher grammage, and wood ash performs better for these types of papers than the other chemical agents utilized. The GSM of rice straw is higher than GSM of sugarcane bagasse.

Tensile Strength

The paper's tensile breaking strength is determined by the highest tension upon failure. Following a NaOH pretreatment, Jani and Rushdan (2016) observed a high tensile index value of 79.57 N•m•g^{-1} for the rice straw paper. In the results below the tensile strength of sugarcane bagasse paper is higher than rice straw due to presence of less lignin and strong binding of fibers.

Burst Index

Paper or paperboard's bursting strength is a composite strength parameter that is influenced by a number of other sheet characteristics, primarily stretch and tensile strength. The kind, quantity, and proportion of fibers in the sheet, as well as the degree of beating and refining, preparation technique, and additive use, all affect bursting strength. The burst index of the rice straw paperboard made in this study improved significantly ($p<0.05$) at successive soaking temperatures of 100 and 155ºC. However, the maximum burst index of the paperboard made in our work was lower than that of most relevant literature (Rodriguez *et al.,* 2009). Burst index of sugarcane bagasse paper is much higher than that of rice straw paper i.e. 5.2 and 0.35 respectively.

Thickness

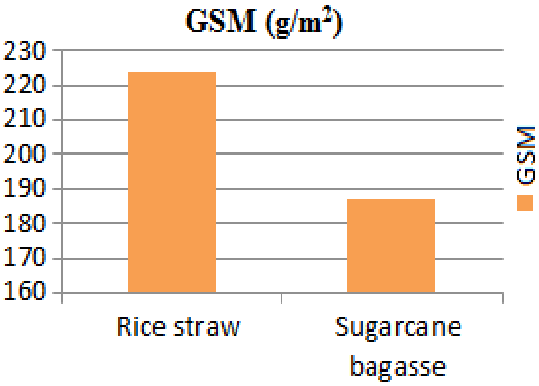
Thickness of rice straw paper is 1.34 mm whereas 1.12mm is analyzed of sugarcane bagasse paper.

Absorbency

Although paper is made of cellulosic material, its water absorbency is caused by cellulose and leftover lignin. It is known that lignin absorbs water two-thirds as well as cellulose (Panshin *et al.,* 1964). This shows that cellulose is mostly responsible for the rice straws' water absorption and that more lignin is eliminated to liberate fibers. Water absorption is enhanced by a more amorphous cellulosic material, and this is inversely correlated with the strength of the fiber bond. The absorbency of rice straw is 0.5 sec higher than that of sugarcane bagasse.

Table 3: Mechanical strength analysis of handmade paper made from agricultural residues

Sr. No	Parameters	Agricultural residues	
		Rice straw	Sugarcane bagasse
1	Gsm (g/m²)	224	187
2	Tensile strength (kn/m)	0.048	0.3
3	Burst index (kpam²/g)	0.35	5.2
4	Thickness (mm)	1.34	1.12
5	Absorbency (g/m²)	3.8	3.2



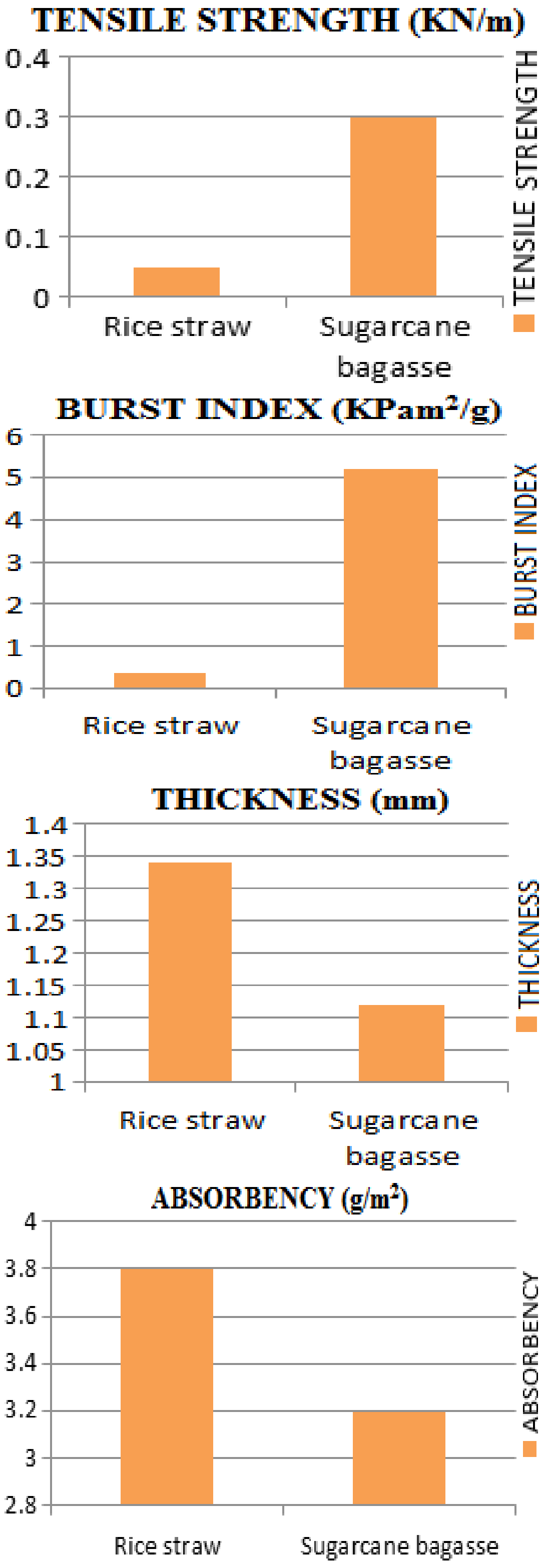


Fig. 7. Different mechanical strength analysis of handmade paper made from agricultural residues

Challenges and future outlook

Fiber Quality

In comparison to wood pulp, the fiber quality of rice straw and sugarcane bagasse is inferior. This makes it difficult to produce high-quality paper, particularly for goods like premium printing paper.

Environmental Considerations

Because it reduces waste and deforestation, the use of agricultural leftovers like rice straw and bagasse is viewed as an environmentally friendly substitute for wood pulp. Nonetheless, there are still issues with the pulping operations' effects on the environment, such as their use of energy and water.

Economic Viability

Processing bagasse and rice straw can be more expensive than typical wood pulping, and there are still financial obstacles preventing widespread commercial adoption.

The manufacturing of paper from sugarcane bagasse and rice straw has become more popular globally, especially in nations with a surplus of agricultural waste. Further adoption is anticipated due to the growing demand for sustainable paper products and advancements in pulping technology, despite issues with pulp quality and processing costs.

Significance of Handmade Paper Production from the Agricultural Residues

Environmental Sustainability

Handmade paper production from rice straw and sugarcane bagasse helps reduce reliance on wood pulp, which is a significant cause of deforestation. By using agricultural waste, it conserves forests and promotes a more sustainable paper industry. Both rice straw and sugarcane bagasse are abundant agricultural by-products. Their use in handmade paper helps reduce the environmental pollution caused by the burning or improper disposal of these residues. For example, rice straw is often burned in fields, leading to air pollution and soil degradation. Using it for paper production mitigates these issues. Handmade paper production generally has a lower carbon footprint compared to industrial paper production. This is because the processes involved in handmade paper production are typically less energy-intensive and use fewer chemicals.

Economic Benefits

Handmade paper production from rice straw and sugarcane bagasse often takes place in rural areas, providing jobs to local communities. This form of paper-making supports the livelihoods of artisans, particularly in regions where rice and sugarcane farming is prevalent. By converting rice straw and bagasse into high-value paper products, farmers and local producers can generate additional income streams. This value addition helps in improving the economic conditions of rural farmers and small-scale manufacturers. Handmade paper, being eco-friendly, has gained popularity in markets that prioritize sustainability. This opens up new business opportunities for artisans, entrepreneurs, and paper manufacturers.

Cultural and Traditional Significance

Handmade paper production is a traditional craft in many cultures, especially in South Asia. In India, the use of agricultural residues like rice straw and sugarcane bagasse for handmade paper aligns with the country's long history of handcraftsmanship. Promoting these eco-friendly alternatives helps preserve cultural heritage while also addressing contemporary environmental issues. Handmade paper is often used in the creation of artisanal goods like journals, greeting cards, stationery, and packaging. This enhances the demand for paper with unique textures and qualities, thus promoting the skill set of local artisans and encouraging the growth of the cottage industry. Artists and designers often prefer handmade paper for its aesthetic appeal and unique texture. The use of agricultural waste in creating paper opens up innovative avenues for sustainable art and design, highlighting the cultural value of environmental stewardship.

Reduction of Agricultural Residue Burning

Rice straw and sugarcane bagasse are often burned in open fields after harvest, which contributes to air pollution and health hazards. By diverting these residues into handmade paper production, the burning of these residues can be minimized, leading to improved air quality and public health. The collection of rice straw for paper production rather than burning also prevents the loss of valuable organic matter that could otherwise be returned to the soil as a natural fertilizer. This helps in improving soil health and preventing land degradation.

Integration with Sustainable Development Goals (SDGs)

Handmade paper from agricultural waste supports SDG 12 by promoting the use of sustainable resources and reducing the negative environmental impacts of paper production. By reducing the need for wood-based pulp, it directly contributes to SDG 13 i.e. climate action by reducing deforestation and associated carbon emissions. Handmade paper production creates economic opportunities in rural areas, especially for marginalized groups, contributing to poverty alleviation and rural development i.e. SGD 1.

Market Demand and Global Trends

With the growing global trend towards sustainability, handmade paper has seen a rise in demand, particularly in markets such as eco-conscious stationery, packaging, and gifting products. As consumers become more aware of the environmental impact of their purchases, they are searching for eco-friendly alternatives. Handmade paper, with its unique qualities, has found niche markets for premium products. From wedding invitations to luxury gift wraps, the demand for such sustainable, aesthetically pleasing paper is growing globally, especially in markets like Europe and North America.

Fig. 8. Significance of handmade papers from agricultural residues in form of decorative sheets

CONCLUSION

A good substitute feedstock for making paper is agricultural residue, which has advantages for the environment and the economy. A number of established processes, such as collecting, pulping (often using soda-AQ pulping), washing, bleaching, and sheet creation, are involved in turning agricultural waste into high-quality paper. This technique is becoming more sustainable and efficient thanks to technological advancements that handle issues like high silica content and seasonal availability. Industries may lessen their need on wood-based pulp, preserve forests, and give rural communities new economic opportunities by using agricultural wastes to make paper.A straightforward but efficient method for turning agricultural waste into premium paper is the laboratory-based manufacturing of handmade paper from rice straw and sugarcane bagasse. Labs can produce sustainable paper products while investigating advancements in waste recycling and green technology by following the aforementioned procedures, which include pulping and final drying. Making handmade paper from rice straw and sugarcane bagasse has several benefits, including social, cultural, economic, and environmental ones. It gives rural communities a means of subsistence, advances sustainable development, and offers an inventive approach to managing agricultural waste. Handmade paper produced from agricultural waste is becoming more and more recognised as a sustainable and desirable product with expanding market potential worldwide as environmental concerns get more attention.

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Conflict of interest

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