

Synthesis of handmade craft-paper from agricultural waste

Yennam Rajesh*, Priyanka Shivde*, Gaurav Daware, Venkat Mane, Vijay Mawal & Sandip Derle

Department of Chemical Engineering, K. K. Wagh Institute of Engineering, Education and Research, Nasik-422003, Maharashtra, India

*E-mail: rajeshiitg09@gmail.com (YR); shivde.priya777@gmail.com (PS)

Received 14 June 2023; accepted 16 May 2024

The present work is to promote the use of agricultural waste (sugarcane bagasse, banana fibers, and rice husk) in the creation of handcrafted paper. This work alters the manufacturing process by utilizing various cellulose ratios derived from different agricultural residues. Craft papers have been made with the use of a fairly straightforward and environmentally benign process known as the handmade technique, which includes these raw residues in various ratios. The physico-mechanical properties are measured for synthesized sheets with an appropriate basis weight ($63\text{--}80\text{ g/m}^2$), thickness ($20\text{--}300\text{ }\mu\text{m}$), burst strength ($58.9\text{--}105.2\text{ kPa}$), burst index ($1.03\text{--}1.67\text{ kPa m}^2/\text{g}$), and bulk ($1.06\text{--}3.12\text{ cm}^3/\text{g}$), respectively. It is demonstrated that the used ingredients are cost-effective and eco-friendly. In addition, it is found that the quality of the handmade paper sample composition formed with a blend of 20% rice husk, 30% sugarcane bagasse, and 50% banana fiber, is relatively high. This study demonstrates that agricultural waste can provide viable alternatives for the industries that produce handmade paper.

Keywords: Agricultural waste, Cost effective, Eco-friendly, Handmade craft paper

Introduction

The paper industry, which is one of the most polluting industries in the world, has recently been under enormous pressure to innovate economically and ecologically viable raw materials. The Indian paper industry faces numerous problems¹. The availability of raw materials of suitable quality in sufficient quantities is a major bottleneck for the industry².

In general, softwood, bamboo, and hardwood are considered important raw materials for high-quality paper and paper products³. Softwood is considered the best raw material due to its long fibers. With population growth, the demand and consumption of paper have increased enormously⁴. Every year, millions of trees are cutting down for various purposes, including paper production. The exact number of trees cut down annually varies, but it is estimated to be around 15 billion trees. This includes trees harvested for paper, lumber, and other wood products. The demand for pulp, paper, and cardboard is around 410 million tons per year worldwide. Paper demand can be estimated at around 529 million tons per year by 2025⁵. The environmental impact of cutting down trees is significant and includes are loss of biodiversity, climate change, soil erosion and disruption of water cycles.

Nowadays, society has become familiar with using more environmentally friendly products and even prefers them to normal products, even though they pay more for the eco-label⁶. Paper is one of the most versatile and widespread products of modern society. The above problems lead to the destruction of our natural forest cover⁷. The limited production of forest-based raw materials, the increased demand for pulp and paper production and the awareness of environmental protection have forced the industry to work with alternative raw materials⁸.

The use of wood and agricultural waste is largely the only raw material for paper production⁹. Disposal of agricultural waste is a major problem due to the presence of cellulose and a high content of lignin, which leads to pollution and affects the environment as these substances are very difficult to degrade⁴. The abuse of natural resources has reached the limits of the earth's resilience. In fact, the life cycle of mill paper harms the environment from start to finish¹⁰. Therefore, the study focuses on alternative environmentally friendly materials for the production of handmade paper. Agricultural commodities such as wheat straw, maize, rice husk, bagasse, *etc.* are used by many medium and large paper mills¹¹. Most medium-sized mills do not have chemical recovery units and discharge large amounts of pollutants from

pulp degradation to the river, along with pollutants from bleaching and other operations¹².

Handmade papermaking is a green and clean industry in the truest sense of the word, as 100% recycled wood-free fibers are used in papermaking. Traditionally, Indian handmade paper makers use cotton rags¹³. The main raw material is processed in a very simplified way without the use of harsh chemicals or conditions. The current scenario of the Swatchh Bharat Mission and the ban on single-use plastic increase the demand for handmade paper and its products. The handmade paper industry is one of the fastest-growing industries in India¹⁴. Paper can be made either synthetically or naturally¹⁵. Synthetic papers are generally preferred for work; however, these papers have adverse effects on the climate and can be substituted with handmade paper. The paper industry is a forest-based industry. The decline in forest cover is a major concern¹⁶. While handmade papers prepared from agricultural waste offer several benefits, such as sustainability and unique textures, they also have some disadvantages including inconsistency in quality, limited production capacity, higher cost, lower mechanical strength, limited availability, limited size and thickness options, and environmental concerns¹⁶.

Making handmade paper has a greater impact on sustainable development since it provides a lot of disadvantaged, rural people with employment opportunities¹⁷. The primary goals of this research are exploring the use of agricultural waste in place of wood for the manufacture of paper¹⁸. Simply put, handmade paper is a sheet of paper that was manufactured by hand. In current study includes the different types of agro residue includes rice husk, sugarcane bagasse and banana fiber¹⁹. The authors have also studied various physical properties of the handmade craft paper. Eco-friendly methodology was used for paper processing from waste. Minimization of wastewater was also main approach in this study. Pulping process of agricultural waste was also carried out by varying different parameters such as alkali ratio, cooking time, etc.

Experimental Section

Materials

In this research work, rice husk, sugarcane bagasse and banana fibers are selected as raw materials and collected from Nashik city, Maharashtra state, India. The sources of rice husk and banana fibers (agro-residue) which are collected from the local farms and

sugarcane bagasse collected from local sugar industries. Sodium hydroxide (NaOH) purity of 97%, (Merck, India), calcium carbonate (CaCO₃) purity of 98%, nitric acid (HNO₃) purity of 68% and potassium chlorate (KClO₃) purity of 80% (Fisher Scientific), distilled water, binding materials (starch/natural glue), pulp machine, blender or mixer, a frame, a roller, and paper cutter, etc. are used in analytical/laboratory grade only.

Methodology

Physico-chemical properties of handmade paper

Agricultural waste was macerated in a solution comprising 1:1 HNO₃ and KClO₃ to determine fibre length. 6 g of KClO₃ was dissolved in 50 mL of 70% HNO₃ and 50 mL of distilled water. A drop of macerated sample was taken on a slide and fiber length was measured under a digital microscope. Using the right software and an image analyser, the cross-section of the snapshot was used to calculate the fibre width²⁰. Table 1, represents the detailed physico-chemical properties of handmade craft paper.

Procedure for synthesis of handmade paper

Mixture of raw materials and addition of binding materials of detailed steps are mentioned below and the whole process is shown in Fig. 1.

Step 1: Raw material collection - Banana fibers, rice husk, and sugarcane bagasse agricultural waste were gathered, dried under the sun over several days, and then cleaned repeatedly with tap water.

Step 2: Cooking time – The raw materials were cooked for 30 min into a pot having 10% NaOH in it.

Table 1 — Physico-chemical properties of hand-made craft paper²²

Properties	Rice Husk	Banana Fibre	Sugarcane Bagasse
Fiber length (mm)	1.41±0.67	2.84	2.30 ± 3.20
Fiber diameter (µm)	4.2 ± 6.34	41.60	19 ± 24.3
L/d ratio	175:1	68.30	30:1
α-Cellulose (%)	29 ± 36	65.18 ± 2.71	46 ± 32
Lignin (%)	12 ± 18.81	13.21 ± 1.04	23 ± 29
Pentosans (%)	23 ± 28	-	-
Hot water soluble (%)	7.3 ± 3.45	3.10 ± 0.62	3.10 ± 0.62
Alcohol benzene soluble (%)	0.6 ± 1.5	3.10 ± 0.27	3.10 ± 0.27
1% NaOH solubility (%)	45.67±57.7	25.35 ± 2.78	15.35 ± 3.78
Ash (%)	6 ± 12	3.20 ± 0.04	1.20 ± 0.04
Silica (%)	9 ± 14	0.7 ± 0.01	1.7 ± 0.01



Fig. 1 — Experimentation of handmade craft paper sheet

Then, the materials were continuously washed with hot water followed by tap water.

Step 3: Blending or mixing process - The pulp was mixed about 5 min using a bit of water into a blender.

Step 4: Bleaching approach (a technique of pulp for cleansing and discoloration) - Clorox was applied to eliminate the dark colour and turn the pulp white.

Step 5: Preparing and ironing of craft sheet – A sheet of paper was prepared with the inlet frame. To enhance the paper properties, additives (CaCO_3 and starch) were included in the pulp in proportions of 0% for the primary paper, 2% for the next paper, and 5% for the remaining papers during this phase. This was the final stage of the paper-making process and used to straighten and smooth the paper.

Step 6: Colouring of craft sheet - The material aluminum was used to make the carrier container for transporting pulp. To make coloured paper, the pulp

was made pink colour. The pulp was left for 15 min in the presence of colour. The pulp was placed on a plain surface once the colour got completely dissolved into the pulp. CaCO_3 and starch were introduced throughout this experiment.

Proximate analysis and physico-mechanical characterisation of handmade paper

According to TAPPI test protocols (given in Supplementary Information), the following characteristics were examined for proximal analysis: Percentage of Moisture (TAPPI, T-258 om-02), weight reduction, content of ash (TAPPI, T-211), Silica (TAPPI, T-244), acetone extractives (TAPPI, T-204), 1% NaOH solubility (TAPPI, T-212), solubility of hot water (TAPPI, T-207), Klason lignin (TAPPI, T-222), acid soluble lignin, T-222 om-88 for lignin, T203 om-93 for α - β - γ -cellulose, T-9m-54 for holocellulose. The variance between the amounts of

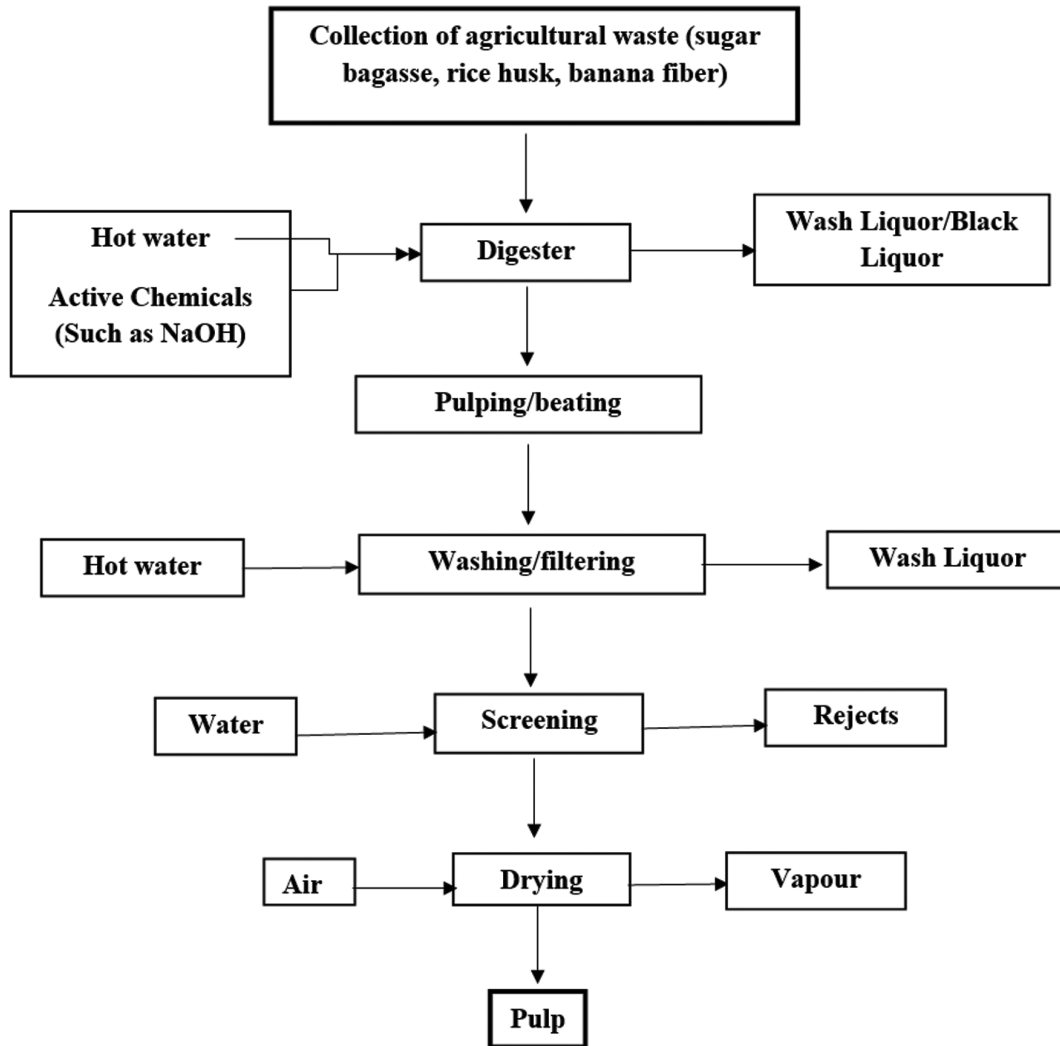


Fig. 2 — Mechanism of agricultural waste pulping

holocellulose and α -cellulose were utilised for determining the hemicellulose percentage^{21,4}. According to the definition of the approved procedure for the test (British norms BS 3137, BS 2922:1, and Global norms ISO 2758 with ISO 2759), the burst indices is the product of a paper's bursting power and its grammage in its conditioned form⁹

$$\text{Burst index (kPa m}^2\text{/g)} = \frac{\text{Burst Strength}}{\text{Basis Weight}}$$

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. Tensile index is calculated in Nm/g (TAPPI, 1988)⁹. Applying an empty micrometre 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 plies³. The unit

of measure for paper texture is GSM (grams per square metre). Ordinary office paper weight 80 g/m², fine paper weighs 100 to 120 g/m², and paperboard weighs 250 g/m² or more¹⁰.

Pulp processing of agricultural waste

To make pulp, a lignocellulosic material with fibers, the fibers of cellulose in wood, fibre agricultural products, scrap paper, other rags were separated either chemically or mechanically. The primary raw material utilised in the production of paper and other industrial paper products, including tableware, was pulp. It was blended with a number of chemical or plant-based ingredients and water. Changes can be made to the standard process for pulping waste from farming as shown in Fig. 2.

Results and Discussion

To regulate the quality of handmade paper, physical examinations of the created sheets were done. The physical test results of eight different handmade paper samples are presented in Table 2, along with a comparison to the industry standard. The study's findings demonstrate that materials including big rice husk, banana fiber, and sugarcane bagasse can be used to make handmade paper.

Analysis of handmade craft sheet paper

The research's non-wood raw ingredients were all, with the exception of bagasse and rice husk, gathered from sources outside the university. Only 400 g were used in the experiment because of this. The paper was dried in the sun. Agro-waste paper was found to dry out soon. While other types of paper dried gradually. The nature of the material and the fineness of the pulp are the main causes of drying.

The papers wrinkled as they dried under the sun. Solar dryers may thereby accelerate this process, minimize paper wrinkles, and minimize the quantity of space required. A tool called a roller (a bottle) was used to properly press and smooth the exterior of the sheet of paper. Rice husk paper shrank the most during drying followed by that with banana fiber and sugarcane bagasse sheet shrank the least.

A visual examination of the handcrafted paper indicates that the colour of the paper varies depending on the substance. Rice husk, sugarcane bagasse, and banana fiber papers all had a uniformly smooth texture. The type of material used and how well it was ground determined the texture. The texture of the agricultural scrap paper hand sheets was highly strong and tearing resistant. The fiber from bananas features visible fiber bundles. The type of raw material used has a significant impact on the quality of the handled sheet and the shrinkage of the paper.

A few flaws were present in the handmade created papers. Both the paper made of mixed agricultural waste and the giant bluestem had dirt on it. This may be due to a discolouration brought on by improper mould cleansing. The sheet paper is created by hand and features crinkles. This might have happened due to improper handling of the pressed sheets. There were a number of uneven sheets on the page. The negligent couching of the paper sheets may have caused this. These flaws could be lessened if adequate attention is used throughout the couching and drying processes.

Interpretation of physico-mechanical properties of handmade craft sheet

Furthermore, grammage, frequently referred to as basis weight, is a basic attribute of paper measured in grams per square metre (GSM). The stiffness and strength of handmade paper are largely influenced by its grammage, which also defines the many paper applications. The average of the replicas created for each sheet with varying amounts of rice husk, banana fibre, and sugarcane bagasse is shown in Table 3, in addition to the findings of other researchers.

As can be observed, the sample utilising the lowest basis weight was produced with 100% agricultural pulp sheet 6 and had a basis weight of 58 g/m², while produced 2–8, exhibited 63–74 g/m². The basic

Table 2 — Proportions of raw materials for synthesis of craft paper

Craft paper sheet No.	Sugarcane bagasse %	Rice husk %	Banana fibre %
1	10	50	40
2	20	30	50
3	30	40	30
4	40	20	40
5	50	10	40
6	30	20	50
7	60	20	20
8	20	20	60

Table 3 — Physico-mechanical properties of hand-made craft paper

Craft paper sample	Weight (g/m ²)	Thickness (µm)	Burst strength (KPa)	Burst index (KPa m ² /g)	Bulk (cm ³ /g)	Reference
1	68	300	78.9	1.16	2.01	Present Study
2	63	180	87.9	1.39	3.02	Present Study
3	72	280	76.9	1.06	2.65	Present Study
4	69	240	88.5	1.28	2.34	Present Study
5	74	210	76.5	1.03	3.12	Present Study
6	58	200	96.5	1.67	2.43	Present Study
7	66	320	82.6	1.25	1.06	Present Study
8	73	290	92.3	1.26	2.90	Present Study
9	68	0.15	-	-	453.33	23
10	80	0.2	-	-	400	20

weights of the samples 1 and 7 were 72 and 69 g/m², accordingly. The Mexican specification for bond sheet NOM-N-70-C-1982 requires this kind of paper to have a grammage of 40-120 g/m². All the paper sheets manufactured with varied proportions of rice husk, banana fibre, and sugarcane bagasse meet the standards²⁴.

The samples, on the contrary hand, belong into the group of papers, corresponding to the mass classification: The papers (7-150 g/m²), cardboards (140-450 g/m²), and cartons (greater than 450 g/m²). While the weight of the evaluated samples differed, all of them fall inside the paper classification since their weights are less than the 125 g/m² defined according to UNE-EN ISO 536:2013²⁵. The variances within the samples were attributable to the handmade and non-standardized manufacturing method of the sheets of paper, in addition to the thickness. This varies based on the quantity of pulp required to create the sheet. Thickness or calliper of paper, on the contrary, is referred to as the parallel distance with the two primary surfaces of the sheet of paper within specified conditions, and determined by measurement with rigid metal plate. Table 3 displays the results of physico-mechanical properties of hand-made craft paper.

The value achieved for treatment paper 6 at 180 mm thickness and 100% agricultural waste is the lowest value. These enormous variations in sheet thickness correlate directly with the power used in their manufacture and the quantity of material coated. When examining the data presented by other authors, it was discovered that the values ranged from 180 to 320 mm for the production of handmade papers from agricultural waste. This suggests that the compression force used during the hand-made sheet's development directly affects its thickness²⁶.

Conclusion

The utilization of agricultural waste for the production of handmade paper offers a sustainable and eco-friendly solution to the environmental challenges posed by the paper industry. In this present study, rice husk, sugarcane bagasse, and banana fibers were used as raw materials for handmade paper production. The physico-chemical properties of the handmade craft paper were thoroughly analysed, and the results indicate that these agricultural wastes can be effectively used to produce high-quality handmade paper. The physical and mechanical properties of the handmade craft paper,

including grammage, thickness, burst index, and tensile index were evaluated. The results demonstrated that the handmade paper samples met industry standards and exhibited suitable properties for various applications. The study highlighted the importance of sustainable practices in the paper industry and showcased the potential of using agricultural waste as an alternative raw material. Handmade paper production not only reduces the environmental impact but also provides employment opportunities, particularly in rural areas. However, further research is needed to optimize the production process and address the limitations associated with handmade paper, such as limited production capacity and higher production costs.

Supplementary Information

Supplementary information is available on the website <http://nopr.niscpr.res.in/handle/123456789>.

References

- 1 Akbari M H R, Use of agricultural waste in the pulp and paper industry, *1st Int 4th Natl Congr Recycl Org Waste Agric*, (2012) 2.
- 2 Saeed H A M, Liu Y, Chen H & Lucia L A, Suitable approach using agricultural residues for pulp and paper manufacturing, *Nord Pulp Pap Res J*, 32 (2017) 674.
- 3 Kishore G H, Atul K & Saakshy A, Role of handmade paper units in improving paper quality and efficiency of recycled waste paper based mills, *J Indian Pulp Pap Tech Assoc*, 13 (2001) 47.
- 4 Alam M, Rikta S Y, Bahauddin K M, Hasnine T & Kamal A K I, Production of eco-friendly handmade paper from wastepaper and other local biomass material research paper production of eco-friendly handmade paper from wastepaper and other local biomass material, *Acad J Environ Sci*, 6 (2018) 147.
- 5 Bhodiwal S, Chauhan S, Agarwal R & Barupal T, A novel approach: Handmade papermaking, *MOJ Ecol Environ Sci*, 7 (2022) 11.
- 6 Jiang S, Li B & Shen Y, The influence of pulp and paper industry on environment, *E3S Web Conf*, 308 (2021) 1.
- 7 Pandita S, Kaula B & Passey S, Use of weeds and agro-based raw materials and their blends for handmade paper making, *DUJ Undergrad Res Innov*, 1 (2015) 169.
- 8 Aswal S, Chauhan S & Bhatnagar P, Identifying efficient isolates of white rot fungi for lignin degradation of calotropis procera fibre in handmade papermaking, *J Sci Res*, 64 (2020) 183.
- 9 Chauhan S, Khan M E, Sharma A K, Jain R K & Hussain G, Cost-effective production of handmade paper through recycling of shredded currency waste of reserve bank of India: An enzymatic route, *J Indian Pulp Pap Tech Assoc*, 21 (2009) 111.
- 10 Jiménez L & López F, Characterization of paper sheets from agricultural residues, *Wood Sci Technol*, 27 (1993) 468.
- 11 Kumar H & Christopher L P, Recent trends and developments in dissolving pulp production and application, *Cellulose*, 24 (2017) 2347.

- 12 Abd-El-Sayed E S, El-Sakhawy M & El-Sakhawy M A M, Non-wood fibers as raw material for pulp and paper industry, *Nord Pulp Pap Res J*, 35 (2020) 215.
- 13 Gupta T & Ahuja V, Bagasse based paper and newsprint in India: Economic and policy issues, 14 (1989) 47.
- 14 Rais M & Sheoran A, Scope of supply chain management in fruits and vegetables in India, *J Food Process Technol*, 6 (2015) 1.
- 15 Laksono P W, Rochman T, Setyanto H, Pujiyanto E & Diharjo K, Design and manufacturing bio composite (Sugarcane bagasse-Polyvinyl acetate) panel that characterized thermal, *Adv Mater Res*, 893 (2014) 504.
- 16 Gonzalez R, Jameel H, Chang H M, Treasure T, Pirraglia A & Saloni D, Thermo-mechanical pulping as a pretreatment for agricultural biomass for biochemical conversion, *Bio Resour*, 26 (2011) 1599.
- 17 Syahrudin N & Kalchschmidt M, Sustainable supply chain management in the agricultural sector: A literature review, *Int J Eng Manag Econ*, 3 (2012) 237.
- 18 Fahmy Y, Fahmy T, Mobarak F, El-Sakhawy M & Fadl M, Agricultural residues (wastes) for manufacture of paper, board, and miscellaneous products: Background overview and future prospects, *Int J Chem Tech Res*, 10 (2017) 424.
- 19 Singh N, Nigam P & Pandey A, Biotechnology for agro-industrial residues utilisation: Utilisation of agro-residues, Published online (2009) 1.
- 20 Román-Gutiérrez A D, Duana-Ávila D, Hernández-Ávila J, Cerecedo-Saenz E, Salinas-Rodríguez E, Rojas-León A & Perea P L, Reuse of barley straw for handmade paper production, *Sustain*, 14 (2022) 1.
- 21 Al-Sulaimani K & Dwivedi P B, Production of handmade papers from sugar cane bagasse and banana fibers in Oman, *Int J Students Res Technol Manag*, 5 (2017) 16.
- 22 Sridach W, The environmentally benign pulping process of non-wood fibers, *Suranaree J Sci Technol*, 17 (2010) 105.
- 23 Arafat K, Nayeem J, Quadery A, Quaiyyum M & Jahan M S, Handmade paper from waste banana fibre, *Bangladesh J Sci Ind Res*, 53 (2018) 83.
- 24 Lam H Q, Bigot Y L, Delmas M & Avignon G, Production of paper grade pulp from bagasse by a novel pulping process, *Appita J*, 57 (2004) 26.
- 25 Haq I, Mazumder P & Kalamdhad A S, Recent advances in removal of lignin from paper industry wastewater and its industrial applications: A review, *Bioresour Technol*, 312 (2020) 123636.
- 26 Yennam R, Neha G, Pachal S, Vaidehi D, Priyanka S & Ganesh G, Agricultural resources in focus: Eco-friendly bioplastic synthesis from corn starch, *Mater Today:Proc*, (2024) (In press).