Biomass Conversion and Biorefinery
https://doi.org/10.1007/s13399-022-03725-1

ORIGINAL ARTICLE

Investigation on potential application of non-wood pulp for hygiene products as absorbent core substantial

R. Divya[1] · T. R. Indumathi[1] · T. Venugopal[2] · C. Prakash[3]

Received: 14 October 2022 / Revised: 22 December 2022 / Accepted: 27 December 2022

Abstract
Compared with woody fibers, natural non-wood fibers also propose some advantages including more porous, fineness, low density, cheapness, and biodegradability. Without a doubt, the majority of the advancement in cellulose-based materials during the past few years has been the separation of microfibrils from plant sources. Among the agro-residual bast fibers, *Helianthus annuus* (sunflower) and *Saccharum officinarum* (sugarcane) are one of the most perceptible fiber crops with superior cellulosic substance. Decortication is the method followed to extract the fiber from the harvested plant stem. The extracted fiber from the plant stem was materialized and investigated after its surface modification by delignification through the kraft pulping process. The inorganic substances were removed from the cellulose fiber to reduce its toughness and to improve its soft, flexible, and liquid absorbency properties. The raw fiber and pulped microfibrils were analyzed under a scanning electron microscope (SEM) which finds the difference in their morphological structure. As beating and grinding of the fiber pulp for wet-laid nonwoven sheet formation were done and a free swell test for pulp was assessed for the absorbency property, it pertains good result ensemble for hygiene products such as cotton and wood pulp.

Keywords Cellulose · Decortication · Delignification · *Helianthus annuus* · Kraft pulping · Microfibrils · *Saccharum officinarum*

1 Introduction

With about 58% of Indian women and girls already using sanitary napkins, women in India currently produce 100,000 tonnes or more of sanitary napkin waste annually. Waste production will rise along with sanitary napkin use [1]. Commercial disposable hygiene products are primarily made of plastic and wood pulp that has been chlorine bleached; this increases the risk of infertility and cervical cancer in some women and is bad for the environment when they are thrown away. Plastic napkins burn frequently during disposal, producing hazardous carcinogenic gases and taking 600–800 years to decompose [2]. Every woman has the ability to produce trash from feminine hygiene products, which has the negative effects of filling up landfills and raising dioxin levels. The average woman is thought to produce 120–150 kg of sanitary waste over the course of her lifetime. In the future, as the consumption of personal care products rises in India, it will be crucial to have access to inexpensive, biodegradable, non-toxic hygiene supplies [3].

This work is concerned with the characterization of pulp extracted from agricultural waste fibers using kraft pulping and wet-laid nonwoven process, which was an efficient technique, for the development of an absorbent core layer for feminine hygiene products. In order to avoid the deforestation for wood in pulping and paper industries, these agricultural waste non-wood plant fibers serve as an alternative resource in the textile industry which are biodegradable and compostable in nature.

These materials are converted into an absorbent core layer for different applications such as to receive, absorb, and arrest the biological fluid of women at different conditions of rest and activity. Nonwoven serves an important role

✉ C. Prakash
dearcprakash@gmail.com

1 Department of Costume Design and Fashion, PSG College of Arts and Science, Coimbatore, Tamil Nadu, India

2 Department of Mechanical Engineering, KGiSL Institute of Technology, Coimbatore, Tamil Nadu, India

3 Department of Handloom and Textile Technology, Indian Institute of Handloom Technology, Fulia, Ministry of Textiles, Government of India, Shantipur 741402, Nadia, West Bengal, India

Published online: 10 January 2023

in the fabrication of this product for high absorption, quick dry, easy availability, low cost, disposal, and compostable property. This agro-waste fibril core product undergoes several test methods with various standards and techniques to evaluate its quality and is found good in commercial markets for chemical-free, biodegradable, waste management, and water conservation performance [4].

The sunflower, or *Helianthus annuus*, is the most well-liked plant worldwide and one of the most economically productive technological crops among agricultural crops due to its high degree of cost-effectiveness and flower seed oil production. Nearly 5 tons of sunflower stalk is obtained in one hectare, as the potential production reaches 125 million tons per year. The bark of stem fibers contains cellulose, hemicelluloses, lignin, and waxes. The third most widely grown oil crop in the world is the sunflower. All the parts of the plant including leaves, flowers, seeds, stem, and root are having high medicinal benefits. The sunflower stem is a reliable remedy for cuts and wounds resulting in a speedy recovery. The bark stem consists of the outer rind and inner pith, where the rind contains 48% cellulose and 14% lignin and the porosity of the bottom stem bark derives around 59% which was suitable for yielding good quality pulp [5].

With over 25 million hectares produced, sunflower-based oil is the fourth highest producing oil crop in the world [6]. The potential production of this byproduct reaches 125 million tonnes when 5 tonnes of sunflower stalks per hectare are taken into account. This potential production tonnage is higher than that of bamboo farming (30 million tonnes, predominantly in Asia and South America), which, together with cotton, is one of the most highly produced sources of commercial fiber in the world, when compared to other natural fibers (excluding wood), farmed across an area of 4.006 lakh ha in India, with an average productivity of 709 kg/ha from 2014–2015 to 2018–2019, and a yield of 2.840 lakh tonnes [7].

Saccharum officinarum (sugarcane) is the grass plant grown in tropical and subtropical countries. Around 1.84 billion tonnes of sugarcane were produced globally in 2017. Both sugar and alcohol mills employ it. However, it cannot be completely eaten by such mills since after being used in those mills, roughly 30% of the pulpy fibrous residue is created. Bagasse is the name for these byproducts. One of the most prevalent agricultural waste products in the world, sugarcane bagasse (SCB), is produced in India on an annual basis in the range of 100 million tonnes [8–10]. Bagasse is a fibrous residue of the sugarcane left after the crushing and extraction process carried out in the sugar mills. Bagasse, a byproduct of the sugar industry, holds a special place among non-wood fibers for pulp manufacturing due to its widespread availability. Ten tonnes of sugarcane waste are typically produced every hectare of sugarcane. Bagasse is diverse in composition as it consists of two heterogeneous fractions—fiber and pith. On fibrous physical nature, the pith cannot be converted into satisfactory pulp due to its small cell dimension. After the removal of the pith, the useful cellulose content in bagasse will be about 55%, and lignin content around 19–20%. Ash content in bagasse is one of the lowest in grass fiber. The sugar mill bears the expense of material collection, crushing, and cleaning, giving it a unique advantage over other non-wood plant fibers [11–13].

These above materials can be completely degraded in soil or, by composting, are softer on the environment than chemical-based products leaning today. Thus, this study is commenced to explore a new way of extracting value from sunflower and sugarcane byproduct (stem) by evaluating their potential as a natural fiber pulp for absorbent core in hygiene products. In this work, renewable eco-friendly non-wood fibers undergo surface modification to obtain fine microfibrils through various processes, fabricated as a nonwoven (wet-laid) constituent, and analyzed for the application of hydrophilic core layer in medical textiles as suitable for feminine hygiene products [14, 15].

2 Materials and methods

2.1 Selection of fiber

2.1.1 Helianthus annuus

This stem fiber is found suitable for processes with the kraft pulping technique. These fibers are characterized by their good hygroscopic nature, wick ability, and excellent permeable properties.

2.1.2 Saccharum officinarum

Among the plant (bast) fibers, bagasse fiber is selected for its excellent properties like biodegradable and recyclable to serve as nonwoven pulp products like wipes, tissues, furfural, etc., in the medical textile industry. A perennial plant called *Saccharum officinarum* has several sturdy, unbranched stems. The outer rind and interior pith of the plant stalk can be distinguished from one another. Longer and finer bundles of fibers are found in the outer part of the rind, while shorter fibers are found in the inner part.

2.2 Collection of fiber

2.2.1 Helianthus annuus

Matured and harvested disease-free sunflower stems were collected from the Agriculture University, Coimbatore, Tamil Nadu, India, of variety AMV 5, at a height of 3 m. The leaves and other plant parts were removed and the isolated stems were collected.

2.2.2 Saccharum officinarum

Sugarcane bagasse was sourced from Tamil Nadu Newsprint Limited (TNPL), Karur, Tamil Nadu, India. The properties and usage of sugarcane bagasse pulp for paper, cutleries, particle boards, etc., were analyzed by the Department of Research and Development in TNPL helping us in progress with pulp production from bagasse.

2.3 Extraction of fiber

The collected *Helianthus* stem was subjected to crushing and beating called the decortication process used for depithing and fiber extraction, in which the inner pith is separated from the outer rind. Then, the fiber is washed thoroughly in water to remove the remaining pith residuals. The cleaned fibers are then dried under sunlight to obtain brittle long fibers. These fibers are chopped to the size of 1.5 inches each. Nearly 20 kg of fiber is extracted and packed in dry bags for research purposes.

2.4 Process of pulping

The extracted fiber was delignified by a kraft pulping process done in the R&D Department, TNPL, Karur. The extracted fibers were cut into pieces of length 1.5 cm, oven dried to remove the remaining water content in the fiber, and weighted for the pulping process. At a specific temperature and pressure, this sort of pulping procedure is chosen for delignification of fiber with white liquor, where it will not affect the inbuilt property of cellulosic fibers and maintain its quality (Table 1). Thus, the moisture content in raw fiber is analyzed and the total volume of liquor and water taken was taken accordingly (Table 1). These recipes of fiber, liquor, and water were added in a rotating digester of capacity 15 l. The temperature needed for pulping of fiber was 160 °C, the time was set for 2–3 h, and the pressure was maintained accordingly.

Table 1 Kraft pulping of *Helianthus annuus* and *Saccharum officinarum* fiber

Specifications	*Helianthus annuus*	*Saccharum officinarum*
Fiber weight with moisture	561 g	543 g
Oven dry weight of fiber	500 g	500 g
Liquor ratio	18% (1500 ml)	16% (795 ml)
Water level	1200 ml	655 ml
Bath ratio	1:4	1:4

After treatment, the pulp was obtained and disintegrated to separate the fiber pulp bundles, then washed thoroughly, drained, and dried using a washcator machine. Furthermore, the pulp was subjected to screening and O_2 bleaching (to avoid chemical bleaching) and the final pulp yield was calculated. The final yield pulp was assessed for its PH and was packed in a poly bag, weighted in a weighing machine, and obtained calculating its inorganic loss and complete cellulose yield.

2.5 SEM analysis

Images of the fiber sample were taken using the general-purpose ultra-high resolution Ultra 55 FE-SEM in this work. To describe the surface characteristics of bast fibers and microfibrils (pulp), Zeiss field emission scanning electron microscopes were used to take SEM micrographs. For good conductivity and high-quality images, the samples were coated with gold (AU/C) before the SEM analysis. The image was taken at a high energy potential of 10,000 kV at a scale of 20 m (various magnifications). The distance between the probe and the sample stub was altered at various levels while taking the sharpness and clarity of the image into consideration. From 100 to 3000X, various magnification levels were used to scan the samples.

2.6 Free swell test

This method is the most conventional, fast, and suitable for limited amounts of samples ($w_0 = 0.1$–0.3 g). The core sample is placed into a tea bag (acrylic/polyester gauze with fine meshes) and the bag is dipped in an excess amount of water or saline solution for 1 h to reach the equilibrium swelling. Then, the excess solution is removed by hanging the bag until no liquid is dropped off. The tea bag is weighed (W_1) and the swelling capacity is calculated by equation. The method's precision has been determined to be around $\pm 3.5\%$.

This approach is the most traditional, quick, and efficient for small sample sizes ($w_0 = 0.1$–0.3 g). To reach the equilibrium swelling, the core sample is put into a tea bag (fine-mesh acrylic/polyester gauze). The tea bag is then submerged in excess water or saline solution for 1 h. The bag is then hung to remove any surplus solution until no liquid is visible. The tea bag is weighed (W_1), and an equation is used to determine the swelling capacity. The precision of the approach has been estimated to be approximately $\pm 3.5\%$.

2.7 Nonwoven fabric formation (wet laid)

Fiber bonding involves weighted 50 g of dry pulp and 500 ml of water entangling a web of loose fibers on a porous sieve screen to form a sheet structure by exposing the fibers to disintegration.

This mixture is dispersed in 1000 ml of water. Then, the sieve with pores less than the pulp fiber size is used to take the wet-laid sheets which were dried under a conditioned room temperature. The formation of the nonwoven wet-laid breathable sheet can be done by an inhouse method, and the final thickness of the sheet, GSM, tensile, tearing, and bursting index along with the breaking strength of the sheet are measured for its stress and strain bearing capability.

3 Results and discussion

3.1 Pulping process

The obtained *Helianthus* fiber pulp was weighted and calculated by the following formula (Table 2).

$$\text{Total wet weight/sample wet weight} \times \text{OD weight obtained} = \text{Total OD weight of fiber pulp} \quad (1)$$

3.2 Total yield of the fiber pulp

After pulping the fiber, it was weighted and calculated for total yield percentage as follows:

Table 2 *Helianthus* fiber pulp

Category of pulp	Weight (g)
Wet weight of fiber pulp	560
Oven dry weight of fiber pulp	230

$$\text{Obtained weight of the OD pulp/taken weight of the OD fiber} \times 100 = \text{Fiber yield percentage} \quad (2)$$

Therefore, 230 g of delignified cellulose fiber is obtained from 500 g of raw fiber and the inorganic substance removal is calculated as 270 g, i.e., 2.1% in total. In the same way, the process was carried out for *Saccharum* bagasse fiber and the final yield was obtained and calculated.

3.3 Scanning electron microscope (SEM) analysis

Images of fiber and microfibril particle samples coated with AU/C were taken using field emission scanning electron microscopy to explore the varied morphologies of cellulosic fiber and pulp microfibrils.

This specimen of *Helianthus annuus* stem fiber and fibril (pulp) is magnified 20 times to examine the structure of the fixed specimen. Figure 1b depicts the disintegrated cellulose fibrils with a high porosity lumen structure after the lignin was removed during the pulping process by cooking with white liquor and water at a specific temperature and pressure. Figure 1a depicts the sample cellulose fiber bonded with lignin. The removal of about 75% of the lignin during this process results in high porosity, which increases liquid absorption.

This study enlarges the *Saccharum officinarum* stem fiber (Fig. 2a) and microfibril (Fig. 2b) specimens to a magnification of 20 m for the analysis of the fixed specimen structure. The fixed specimen structure was found to be composed of several folded layers with a highly porous structure that has a tendency to absorb

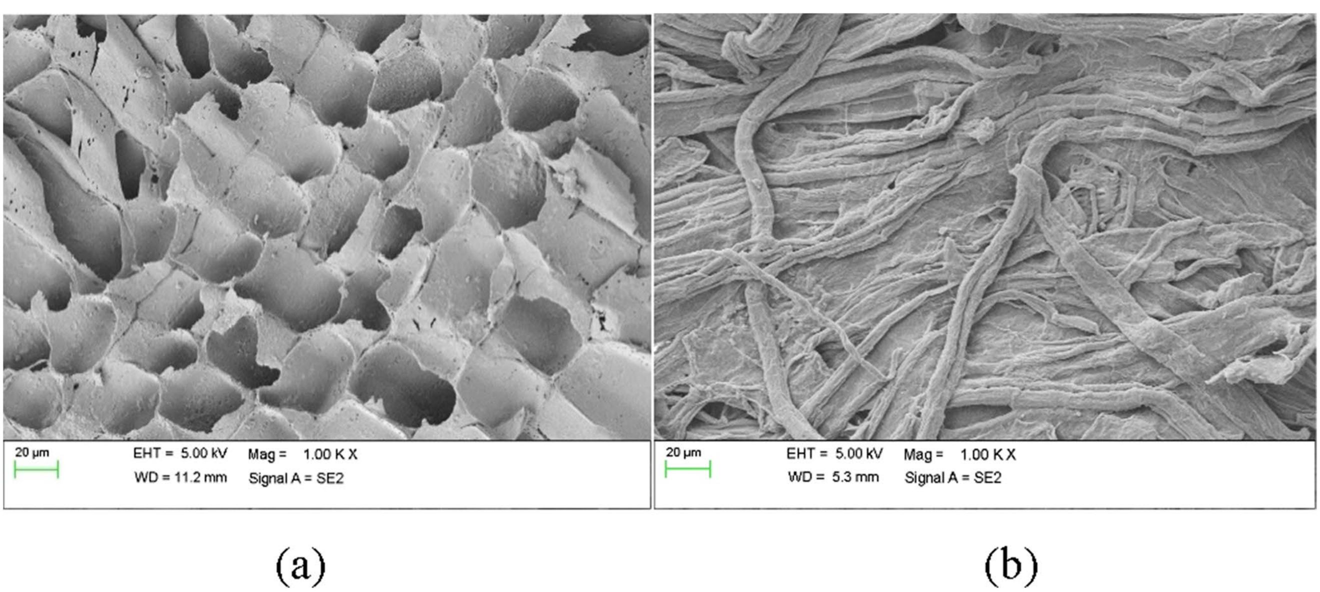

Fig. 1 SEM analysis of **a** *Helianthus annuus* stem fiber and **b** microfibrils (pulp)

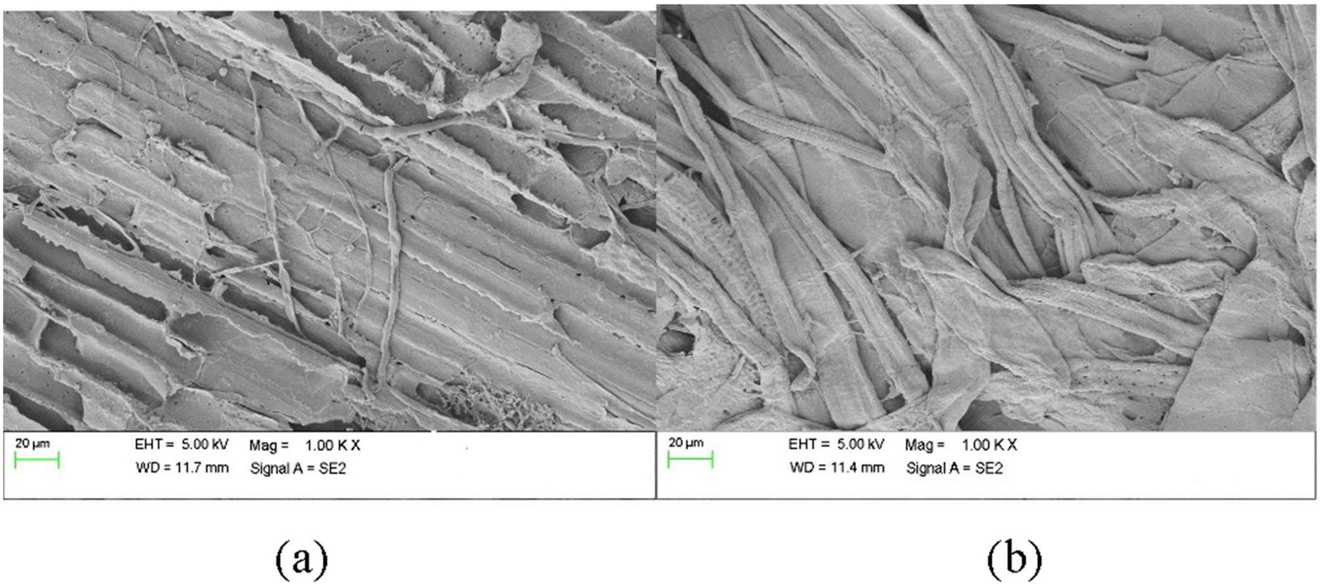

Fig. 2 SEM analysis of **a** *Saccharum officinarum* stem fiber and **b** microfibrils (pulp)

more liquid and swells with the molecules as microfibrils at the pulp stage. Figure 2a depicts the isolated and identified cellulose fibrils with significant diameter, characterized by high porosity, as a result of the removal of lignin during cooking with white liquor and water at certain temperatures and pressures with regard to the pulping process. Figure 2b depicts the sample cellulose fiber bonded with lignin. The lignin is removed during this procedure, with the remainder going through screening and bleaching. The fiber structure is altered during pulping, which increases liquid absorption.

3.4 Free swell test

To ascertain the liquid penetration and quantity with retaining capacity, cellulose fibrils' free swelling is an outcome of the liquid sorption process. For its swelling capability, the cellulosic fiber pulp used in the hygiene product's center core underwent testing in accordance with ISO: 17,190–5. The fibers were initially weighed at 5 g, and the ideal sorption time and level are indicated. By using the tea bag method in the SITRA laboratory, this was done to ascertain the degree of absorption of the *Sabdariffa* and *Saccharum officinarum* fibril pulp present as the core. The valuable result is shown below.

The absorbent layer (*Helianthus annuus and Saccharum officinarum*) achieves an excellent absorbing capacity of roughly 60–70%, serving as the product's core layer and holding onto the fluid for an extended period of time, as shown in Table 3. These agro-residual pulps will therefore serve as a great absorbent component for personal care and hygiene products.

Table 3 Evaluation of *Helianthus* and *Saccharum* fiber pulp for liquid absorption property

Free swell absorptive capacity	Core (grams/gram)
Helianthus annuus fiber pulp	9.08
Saccharum officinarum fiber pulp	10.70

3.5 Wet-laid hand sheet analysis

The wet-laid sheets of both the fiber pulp were oven dried and analyzed according to the TAPPI standard as the results were compared for bestowing physical performance.

The result shown in Table 4 reveals that *Saccharum officinarum* pertains good in physical and strength properties when compared to the *Helianthus annus* pulp sheet for the application of a composite absorbent core layer in feminine hygiene products.

4 Conclusion

The main quality of the material utilized in hygiene products is absorbency. The raw material for this study's extraction and modification of microfibrillated cellulose was non-wood plant fibers (MFC). This investigation's major goal is to determine how well cellulose fiber works with hydrophilic layers in hygiene products. Both fibers show only slight variations at immersion and display fairly high contact angle against water. In advance credit, the delignifying process tends the fiber to obtain fineness, flexibility, and liquid absorbency properties.

Table 4 Nonwoven wet-laid pulp sheet analysis

S.NO	Sheet properties	Measures	
		Helianthus annus	*Saccharum officinarum*
1	Thickness (mm)	0.21	0.13
2	Grams per square meter (GSM)	200	140
3	Tensile index (Nm/g)	50	62.25
4	Tear index (mNm^2/g)	4.97	5.05
5	Burst index ($kPam^2/kg$)	2.43	3.81
6	Breaking strength (MPa)	5097	6350

The removals of 90% inorganic compounds like lignin, wax, ash, etc., from the fiber were inveterate by weighing the resultant pulp obtained, SEM analysis, and free swell test. The final fiber pulp was disintegrated and formed into wet-laid nonwoven for the conversion of the hand sheet which will be then added with Bio SAP for more liquid absorbency and lessen napkin thickness in further conduct. Thus, the consumption of residual cellulosic fiber as an alternative for cotton or wood pulp for hygiene personal care products measured good results and will be preferable for future developing composite absorbent products.

Author contribution Conceptualization—TRI, RD, and TV; investigation and data interpretation—TRI and RD; writing-original draft preparation and methodology—TRI and TV; writing review and editing—CP.

Data availability Not applicable.

Code availability Not applicable.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication All authors agree to the publishing of the paper.

Conflict of interest The authors declare no competing interests.

References

1. Pathak N, Pradhan J (2016) Menstrual management and low-cost sanitary napkins. Econ Polit Wkly 51:27–29
2. Brodin FW, Lund K, Brelid H, Theliander H (2012) Reinforced absorbent material: a cellulosic composite of TEMPO-oxidized MFC and CTMP fibres. Cellul 19:1413–1423. https://doi.org/10.1007/s10570-012-9706-4
3. Guo D, Huang S, Zhu Y (2022) The adsorption of heavy metal ions by poly (amidoamine) dendrimer-functionalized nanomaterials: a review. Nanomate 12:1831–1839. https://doi.org/10.3390/nano12111831
4. Fahmy Y, Fahmy TY, Mobarak F, El-Sakhawy M, Fadl M (2017) Agricultural residues (wastes) for manufacture of paper, board and miscellaneous products: background overview and future prospects. Inter J Chem Tech Res 10:424–448. https://doi.org/10.5281/zenodo.546735
5. Alila S, Besbes I, Rei Vilar M, Mutji P, Boufi S (2013) Non-wood plant as raw materials for production of microfibrillated cellulose (MFC): a comparative study. Ind Crops Prod 41:250–259. https://doi.org/10.1016/j.indcrop.2012.04.028
6. Chen JH, Lu XF (2006) Progress in bio-fuel combustion in circulating fluidized bed boiler. Trans Chin Soc Agric Eng 22:267–270
7. Faruk O, Bledzki AK, Fink HP, Sain M (2012) Biocomposites reinforced with natural fibers: 2000–2010. Prog Polym Sci 37:1552–1596. https://doi.org/10.1016/j.progpolymsci.2012.04.003
8. Chandel AK, Da Silva SS, Carvalho W, Singh OV (2012) Sugarcane bagasse and leaves: foreseeable biomass of biofuel and bio-products. J Chem Technol Biotechnol 87:11–20. https://doi.org/10.1002/jctb.2742
9. Konde KS, Nagarajan S, Kumar V, Patil SV, Ranade VV (2021) Sugarcane bagasse based biorefineries in India: potential and challenges. Sustain Energ Fuel 5:52–78. https://doi.org/10.1039/D0SE01332C
10. Pandey A, Soccol CR, Nigam P, Soccol VT (2000) Biotechnological potential of agro-industrial residues. I: sugarcane bagasse. Bioresour Technol 74:69–80. https://doi.org/10.1016/S0960-8524(99)00142-X
11. Deng C, Liu W, Zhang Y, Huang C, Zhao Y, Jin X (2018) Environmentally friendly and breathable wet-laid hydroentangled nonwovens for personal hygiene care with excellent water absorbency and flushability. R Soc Open Sci 5:171486. https://doi.org/10.1098/rsos.171486
12 Barbash V, Trembus I, Alushkin S, Yashchenko O (2016) Comparative pulping of sunflower stalk. Sci J Sci Rise 3:71–78. https://doi.org/10.15587/2313-8416.2016.63098
13. Cueva-Orjuela JC, Hormaza-Anaguano A, Merino-Restrepo A (2017) Sugarcane bagasse and its potential use for the textile effluent treatment. Dyna 84:291–297
14. Yue F, Chen KL, Lu F (2016) Low temperature soda-oxygen pulping of bagasse. Molecule 21:85–94. https://doi.org/10.3390/molecules21010085
15. Indumathi TR, Divya R (2021) Development of microfibril substantial for hygiene products using compostable agro-residuals. J Fiber Sci Technol 77:305–309. https://doi.org/10.2115/fiberst.2021-0033