Review Article

Utilization of Non-Wood Fibers as Raw Materials for Pulp and Paper Production in Pakistan: A Review

Muhammad Umair Khan[1]*, Abdur Rehman[1], Mansoor Ali Khan[1], Abdur Rahman Khan[1], Sajid Ali[1] and Zeeshan Ahmad[2]

[1]Pakistan Forest Institute, Peshawar, Khyber Pakhtunkhwa, Pakistan; [2]Department of Industrial Engineering, University of Engineering and Technology Peshawar, Khyber Pakhtunkhwa, Pakistan.

Abstract | Pulp and paper raw materials are in huge demand due to the growth of the pulp and paper sector in Pakistan and around the world. Because of scarce forest resources and abundance of agricultural leftovers, Pakistan has a great opportunity to produce pulp and paper utilizing raw materials of non-wood. In nations where the supply of wood for this industry is declining, the utilization of non-wood for pulp and paper production has increased. Three groups of raw materials are used in the manufacturing of paper: non-wood, wood, and recycled wastepaper. Utilization of non-wood resources in pulp manufacturing have several advantages, including easier pulping, lower energy use, the preservation of forest reserves and improved management of agricultural waste. The use of fibers of non-wood plants in paper production is also linked to a number of issues, such as collection, transportation, challenges of chemical recovery, alteration of morphological properties and slow water retention. The main consumers of non-wood fibers, small mills, usually have poor pollution control systems. Non-wood materials are now a more viable option as raw materials for papermaking due to a number of considerations. Several pulping methods can be used for non woody raw material such as soda/soda anthraquinone and organosolv. The availability and utilization of raw materials of non-wood for Pakistan's pulp and paper sector is examined in this study. Non-wood fibers offer a variety of physicochemical characteristics that make them a viable raw material substitute for Pakistani pulp and paper manufacturers.

Received | October 04, 2023; **Accepted** | October 11, 2024; **Published** | October 26, 2024
***Correspondence** | Muhammad Umair Khan, Pakistan Forest Institute, Peshawar, Khyber Pakhtunkhwa, Pakistan; **Email:** umairicp7@gmail
Citation | Khan, M.U., A. Rehman, M.A. Khan, A.R. Khan, S. Ali and Z. Ahmad. 2024. Utilization of non-wood fibers as raw materials for pulp and paper production in Pakistan: A review. *Pakistan Journal of Forestry,* 74(2): 53-62.
DOI | https://dx.doi.org/10.17582/journal.PJF/2024/74.2.53.62
Keywords | Non-wood fiber, Raw material types, Suitability, Pulp and paper production

Introduction

The global as well as Pakistan's pulp and paper industries have been experiencing rapid growth, leading to a substantial surge in demand for raw materials used in their production. Paper and pulp mills provide a wide range of goods for different uses, making them essential to both the national and international economies. Pakistan is poor in forest cover. Most of the raw material is imported to meet the demand. However Pakistan is an agriculture country which produces a large amount of fruits, vegetables, cereals and agriculture residues. These residues can be utilized as a source of fibers in the production of pulp, paper and paperboards. The past few decades have seen a constant rise in the use of paper in wealthy nations like Japan, the European Union, and the United States, due to the rapid industrial expansion and urbanization (Latta *et al*., 2016). Due to the increasing demand, Concerns about the environmental consequences of forest harvesting have increased the pressure on logging (Ashori, 2006; Madakadze *et al*., 2010; Mossello *et al*., 2010). Consequently, there is a necessity for affordable alternative raw materials and processes. Non-wood fibers, like those found in annual plants and agricultural waste, offer potential sources for making pulp and paper with desirable qualities (Rosa *et al*., 1999; Sridach, 2010), especially in countries with insufficient forest resources (Cappelletto *et al*., 2000).

Using agricultural remains and the residues of weed plants can help to meet the rising need of paper in the packaging industry as well as health and hygiene items like towel of paper, toilet paper, and disposable wipes of makeup (Adel *et al*., 2016; Mousavi *et al*., 2013). Non-wood raw materials serve as a key fiber resource in regions with limited forest resources. Using plant fibers that are not wood, such as bagasse, rice straws, corn stalks, and cotton stalks, can help increase the amount of raw materials that are available for manufacturing paper. Wood accounts for around 90% of the total production of chemical and mechanical pulps around the globe, whereas less than 10% of paper and pulp are produced from raw materials of non-wood (El-Sakhawy *et al*., 1996). Approximately 18% of bagasse, 44% of straw, 13% of bamboo, 14% of reeds and 11% of other resources make up non-wood pulp. The two main nations where non-wood pulp is produced in large quantities are China and India (Oinonen and Koskivirta, 1999). China alone produces 70% of the world non wood pulp production.

In countries like China, India, and Egypt where there are little forest resources, a wide variety of non-wood plant fibers are vital as fiber supplies and are gradually becoming more significant in these locations (Laftah and Rahman, 2016). Therefore, the future fiber shortage that is anticipated could be resolved with use of non-wood resources. The utilization of forest resources in a variety of businesses, including the production of paper, building and furniture, has significantly increased in recent years. Fibrous wood is used extensively in the paper and pulp sector. There are significant environmental problems linked to this strong reliance on fibrous wood including: forest destruction, emission of GHGs and rise in global temperature (Ashrafi *et al*., 2015). Due to this increasing global demand for raw materials of fibers, the shortage of plants in numerous countries and the increasing awareness of sustainability, agricultural crop residues (non-wood) have emerged as one of the great significant alternative resources (Bhardwaj *et al*., 2019; Gharehkhani *et al*., 2017). Currently, the utilization of these residues is not a wise practice since they are often burned in open land with inadequate control measures, leading to severe environmental consequences due to generation of heavy smog (Kong *et al*., 2012). Because these wastes are sustainable and reasonably priced sources of cellulosic fiber, they could provide a competitive alternative to woody lignocellulose biomass if used properly. Their remnants show structural resemblances to other plant fibers used in paper manufacturing with similar composition and physical and chemical properties (Jiménez *et al*., 2005).

Types of fibers of non-wood for pulp and paper production

Three categories of lignocellulosic fibers are commonly used in the manufacturing of pulp and paper: Recycled fibers, non-wood, and wood. Non-wood was the word created to distinguish it from hardwoods and softwoods, the two main sources of wood fiber. Based on the kind of pulp to be made, non-wood plant fibers have been divided into two general categories: Specialty fibers (softwood substitutes) like flax, sisal, kenaf, bast fibers, hemp, bamboo, abaca, and Common non-wood fibers like cereal straws, grasses, bagasse, bamboo, and reed sand (Hurter and Eng, 2002). The potential sources of non-wood fibers for the production of paper have been categorized into three distinct groups: (1) crop residues derived from point source processing centers, (2) residues from food crops, and (3) crops cultivated solely for their fiber content (Rowell and Cook, 1998).

Among the three general sources of raw material, wood fibers from trees remain dominant of others two. The paper manufactured from any of the three clusters mentioned above retains its fabric-like nature, formed by dewatering a semiliquid comprising cellulosic fibers. In essence, this procedure includes the lignin of slurry and, often, hemicellulose being removed. The processing stages in papermaking based on type of raw material are illustrated in Figure 1 (Yadav *et al*., 2020).

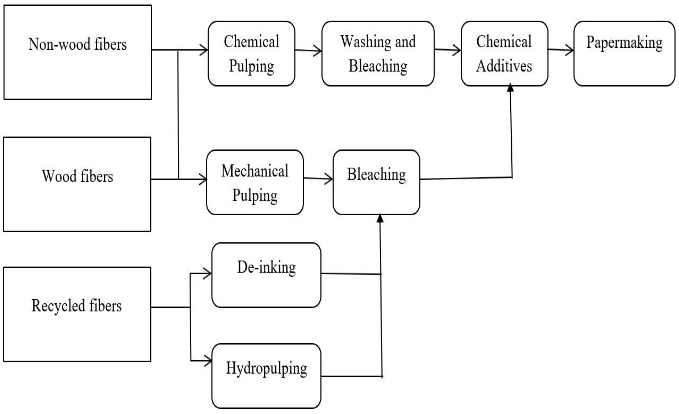

Figure 1: *Papermaking process of different raw material.*

Advantages of non-wood

The utilization of non-wood resources in the production of pulp offers advantages like easy pulping, the provision of exceptional fibers suitable for specific paper types and the creation of high-quality bleached pulp. In farms, a variety of non-wood fibers from annual plants can be produced and collected annually with large yields of up to 3–18 tonnes per hectare (Saijonkari-Pahkala, 2001). In comparison to wood species, non-wood species used in papermaking have a rapid growth rate, resulting in quicker returns to the cultivators. The greatest advantage of incorporating agricultural residues like straw, bagasse, corn stalks and cotton stalks in mills of pulp is twofold. Firstly, it facilitates the efficient disposal of waste materials before harvesting of new crops. Secondly, farmers can earn additional income through this utilization process.

By utilizing these resources, it becomes possible to produce high-quality bleached pulp through a less polluting process compared to hardwood pulp (Johnson, 1999) and with less requirement of energy (Rezayati-Charani *et al*., 2006). Along with other many countries across the globe, Pakistan has also fewer forest cover thus, the utilization of non-wood fibers can be served as a viable alternative to the continuously depleting forest wood resources (Jiménez *et al*., 2007). Therefore, it is clear that establishing new local sources of pulping and raw materials in Pakistan would not only result in lower imports but also provide financial incentives to the industrial and agricultural sectors of the country with less environmental and energy burden.

Challenges of non-wood

The utilization of agricultural residues presents some challenges which are not easy to handle. A significant obstacle in introducing fibers of non-wood into the paper sector and industry is the logistics requirement for collection. The cultivation of non-wood sources occurs in dispersed locations, making the collection of raw materials challenging. Consequently, pulp mills utilizing non-wood materials must be kept relatively small to minimize the transportation expenses associated with collecting these raw materials. Non-wood paper mills, as typically operating on a smaller scale, often face financial constraints that prevent them from investing in a proper recovery system. As a result, these mills release their effluents directly into the environment.

An additional difficulty associated with non-wood plant materials is that their chemical composition and morphology are subject to vary with harvesting seasons due to factors including harvesting or cutting time, geographical place and plant breeding (Young, 1997). Moreover, Ash and silica content are normally higher in non-wood fibrous material (Hurter, 1988). The majority of silica tends to dissolve during the alkaline cooking process which later contributes to various issues within the chemical recovery procedure. It results in reduced effectiveness of certain equipment, heightened viscosity of the black liquor and blockage of tubes; posing challenges in pumping the liquor to specific segments of the retrieval process. These issues make the process of chemical recovery challenging, costly and less effective in comparison to the black liquor recovery from wood (Moore, 1996). Moreover, non-wood fiber material retains water more slowly than woody material does, which complicates the processes of washing, screening and paper machine operation.

Reasons for utilizing fibers of non-wood in pulp and paper sector of Pakistan

Quickly expanding paper sector

The population and economic growth of Pakistan have led to an increase in need for paper and paperboard products. With a total installed capacity of 1,050,499 metric tons annually, the paper industry of Pakistan is made up of more than 57 pulp and paper factories. Most of the raw material for the production is imported from different countries. This import can be reduced by utilizing the agriculture residue which is abundantly found in Pakistan.

Shortage of wood fiber

In Pakistan, using non-wood plant fibers to produce pulp and paper is not an option it is a need. Because this country is not rich in forest resources. Only 4.8% of Pakistan's total land area is covered by forest which indicates a lack of forest resources appropriate for pulp manufacturing. Because of the growing need for wood fibers in the pulp and wood industries, this shortage becomes even more severe. So, the virgin wood has an important role in fulfilling the demand of forest products. However, several parts of Pakistan have limited forested areas, making the availability of non-wood fibers for the production of pulp and paper necessary rather than optional.

Special papermaking properties of selected non-wood fibers

Certain non-wood plant fibers are in demand due to their unique properties which make them superior to wood fibers, especially for specialty paper production. The applications of Bagasse pulp are found in a wide array of paper types such as bag, wrapping, printing, writing, toilet tissue, toweling, glassine, corrugating medium, liner board, bleached boards and coating base stocks (Atchison, 1993). Premium letterhead paper, currency paper, dissolving pulp and several more specialty products can all be made with cotton linters (ATEŞ *et al*., 2015). Hardwood chemical pulp for writing and printing can be substituted from Bagasse and straw due to their excellent formation to paper (ATEŞ *et al*., 2015; El-Sakhawy *et al*., 2018). Wheat straw has shown a good indication in the proper supply for writing and printing paper (Kaur *et al*., 2018). Pulps formed from non-woody annual plants, such flax, kenaf, bagasse and rice and wheat straw can function well as reinforcing fibers in pulps derived from waste paper.

Non-wood fibers availability

Agriculture residue is available locally at a very low price or even free of cost but the main cost associated with it, is the cost of transportation and collection. Due to huge amount of agriculture wastes, it is not easy to handle. Also due to its manual collection, it acquires huge labor cost ratio to the raw material cost. Therefore, the countries with lowest labor wages, the use of these raw material can be extremely suitable in pulp manufacturing as compare to wood pulping (Gominho *et al*., 2018).

Over view of agriculture sector of Pakistan

The agricultural sector of Pakistan plays a vital role in its economy. Its contribution to the total GDP is 22% and the total workforce absorbed is 42%. Year-wise Agriculture Contribution and Labor Employed in Agriculture Sector of Pakistan is illustrated in Figure 2 (Possible usses of crop residue for energy generation instead of open burning, December, 2019).

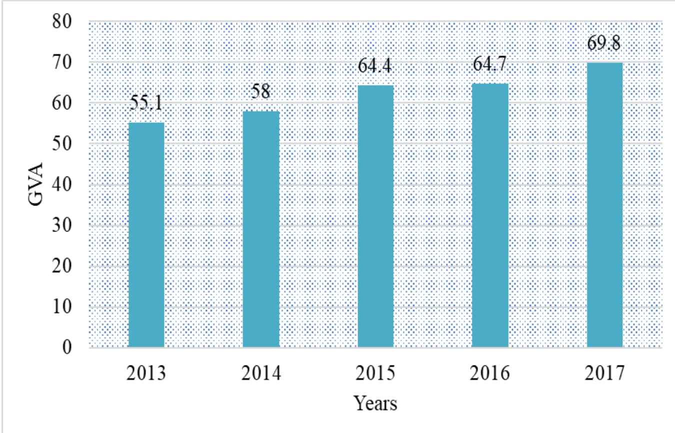

Figure 2: *Pakistan year wise agriculture gross value added (USD Bn).*

Pakistan accounts 40.2 % Agriculture land of its total land. The agriculture land distribution by crops illustrated in Figure 3 shows that sugar cane is the highest crop produced as compare to other crops in Pakistan which is 63% of the total crop production (Possible usses of crop residue for energy generation instead of open burning, December, 2019).

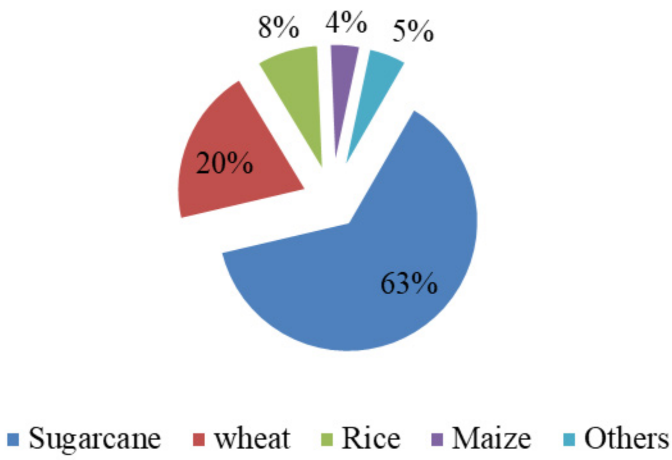

Figure 3: *Total crop production (Total: 129 million tons) in Pakistan.*

Pakistan has a potential of cultivation of major crops including wheat, maize, rice, sugarcane and cotton etc. The annual production of major crops of Pakistan and their generated residues are tabulated in Table 1 (Possible usses of crop residue for energy generation instead of open burning, December, 2019).

Table 1: *Crop residue potential in 2017-18 in Pakistan.*

Crop	Annual production (000 Tons)	Gross residue generated (000 Tons)	Surplus residue potential (000 Tons)
Wheat	25,490	45,882	10,294
Rice	10,320	17,544	4,912
Maize	5,700	13,110	3,278
Coarse cereals	504	907	200
Cotton	1,935	7,353	4,559
Sugarcane	81,102	32,441	12,652
Pulses	125	250	95
Oilseeds	3,555	5,333	1,600
Total	128,731	122,820	37,389

Agriculture residues characterization

In comparison of wood fibers, non-wood fibers have vided range of physicochemical properties. Other than having a higher quantity of hemicellulose, silica, and nutrients than wood, non-wood fibers possess certain crucial physical characteristics such as low bulk density, high fiber content and short fiber length. For instance, sugar cane has 74% holocellulose and roughly 45% cellulose by dry matter, compared to 45% of hardwood fibers (Peng and Sirnonson, 1991). Other materials that are frequently used in the manufacturing of writing and printing paper include rye, kenaf, hemp, jute, and reed (Ashori, 2006). The fiber morphology of commonly used agricultural fiber-rich materials and their chemical characterization are shown in Tables 2 and 3, respectively.

Table 2: *Fiber characteristics of some important agriculture residue.*

Agriculture residue	Wall thickness (µm)	Lumen diameter (µm)	Fiber width (µm)	Fiber length (mm)	Reference
Sugarcane bagasse	5.63	9.72	20.96	1.59	(Samariha and Khakifirooz, 2011)
Banana fiber	5.2	29.4	41.6	2.84	(Ogunsile and Oladeji, 2016)
Barley straw	4.07	6.97	15.26	0.67	(Tsalagkas *et al.*, 2021)
Canola straw	7.43	11.9	28	1.21	(Yousefi, 2009)
Coconut husk/coir fibers	2.91–4.02	10.71–12.97	17.52–20.68	0.69–1.06	(van Dam *et al.*, 2006)
Coconut husk/coir fibers	4.41	13.59	20.09	0.84	(Main *et al.*, 2014)
Coconut husk/coir fibers	3.3	10.71	17.6	0.67	(Tsalagkas *et al.*, 2021)
Sunflower stalk	5.85	11.12	22.84	0.96	(Kiaei *et al.*, 2010)
Sunflower stalk	5.9	11.9	23.7	0.96	(Rudi *et al.*, 2016)
Kenaf bark	4.2	11.9	21.9	2.32	(Ververis *et al.*, 2004)
Kenaf fiber (core)	4.3	13.2	22.2	0.74	(Thiruchitrambalam *et al.*, 2012)
Maize stalks	2	4.4	8.4	1.52	(Garay *et al.*, 2009)
Maize stalks	4.19	10.92	20.12	0.88	(Kiaei *et al.*, 2010)
Maize stalks	8.82	13.67	30.19	1.52	(Ekhuemelo and Tor, 2013)
Maize Husk	8.82	13.67	30.19	1.37	(Ekhuemelo and Tor, 2013)
Maize straw	3.68	9.73	17.18	0.75	(Tsalagkas *et al.*, 2021)
Miscanthusgiganteus stalks	4.64	5.76	15.17	0.5	(Tsalagkas *et al.*, 2021)
Rapeseed straw	1.17	23.02	12.5	5.26	(Enayati *et al.*, 2009)
Rapeseed straw	4.31	15.5	24.12	0.95	(Kiaei *et al.*, 2010)
Rapeseed straw	2.25	8.6	13.1	1.2	(Tofanica *et al.*, 2011)
Rapeseed straw	4.91	19.1	28	1.03	(Tofanica *et al.*, 2011)
Rapeseed up	4.25	9.73	18.36	0.71	(Tsalagkas *et al.*, 2021)
Rapeseed low	3.86	11.04	18.99	0.57	(Tsalagkas *et al.*, 2021)
Rice straw	3.02	4.52	10.77	0.54	(Tsalagkas *et al.*, 2021)
Rice straw	1.5	1.9	4.9	0.66	(Garay *et al.*, 2009)
Rice straw	3.16	4.57	10.89	0.83	(Kiaei *et al.*, 2010)
Rice straw	1.83	5.6	11.6	0.78	(Ferdous *et al.*, 2021)
Sugarcane	NA	NA	19.35–20.96	1.22–1.59	(Hemmasi *et al.*, 2011)
Sugarcane bagasse	4.5	10.25	19.86	1.15	(Tsalagkas *et al.*, 2021)
Sugarcane bagasse	1.6	5.2	8.4	1.7	(Khristova *et al.*, 2006)
Sugarcane bagasse	7.74	6.27	21.4	1.51	(Agnihotri *et al.*, 2010)
Sugarcane bagasse	5.64	9.72	20.96	1.59	(Hemmasi *et al.*, 2011)
Sunflower stalk	4.8	13.23	22.99	0.64	(Tsalagkas *et al.*, 2021)
Wheat straw	4.59	4.02	13.2	0.74	(Deniz *et al.*, 2004)
Wheat straw	4.13	8.34	16.87	0.78	(Tsalagkas *et al.*, 2021)
Wheat straw	1.6	6.8	9.9	0.85	(Garay *et al.*, 2009)

Table 3: *Proximate chemical analysis of some important agriculture residue.*

Agriculture residue	Holoce Llulose (%)	Klason lignin (%)	Hot water solubility (%)	Cold water solubility (%)	Alcohol benzene solubility (%)	1 % NaOH solubility (%)	Ash (%)	References
Barley straw	66.01	19.47	16.25	11.01	8.71	56.25	11	(ATEŞ *et al*., 2015)
Cornstalk	69.92	18.16	16.82	14.64	8.57	46.43	7.75	(ATEŞ *et al*., 2015)
Cotton stalk	62.79	23.79	17.91	15.05	8.36	48.88	4.99	(ATEŞ *et al*., 2015)
Hemp	86.08	6.42	5.85	5.29	1.59	20.04	3.62	(ATEŞ *et al*., 2015)
Cornstalk	82.1	7.3	12.6	NA	NA	69.6	24.9	(Daud *et al*., 2016)
Empty fruit	80	17	3.5	NA	2.3	NA	3.5	(Khalil, 2011)
Oil palm	83	21	4.5	NA	2.3	NA	2.5	(Khalil, 2011)
Oil palm	73	25	5.5	NA	1.3	NA	2.5	(Khalil, 2011)
Reed stalk	78.85	22.79	9.8	7.61	3.26	36.81	4.17	(ATEŞ *et al*., 2015)
Rice straw	60.7	12–16	7.3	9.66	0.6	57.7	15–20	(ATEŞ *et al*., 2015)
Rye straw	76.95	17.25	15.72	11.95	7.44	44.35	4.01	(ATEŞ *et al*., 2015)
Sunflower	66.85	14.43	24.26	21.08	7.48	50.05	7.99	(ATEŞ *et al*., 2015)
Tobacco stalk	64.29	15.15	21.56	17.15	8.06	50.57	14.4	(ATEŞ *et al*., 2015)
Wheat straw	69.84	22.33	14.71	11.33	9.33	53.67	11.6	(ATEŞ *et al*., 2015)

Pulping processes of non-wood

Pulping is actually the separation of fibers by dissolving lignin content among them using mechanical, chemical or both methods (Tian *et al*., 2019). Mechanical Pulping uses mechanical energy for fiber separation from one another, causing sluggish disturbance in the connectivity of fiber, discharging fiber bundles, single fibers and fiber fragments (Sandberg *et al*., 2020). On the other hand, chemical pulping use chemicals that make the lignin water-soluble by breaking down its bond in order to get the separated fibers. Due to its capacity to preserve the biomass of the fibers and improve undried fibers conformability and flexibility, chemical pulping is typically chosen over other pulping techniques (Fearon *et al*., 2020).

For pulping agricultural residue, the most world widely used chemical pulping method is soda pulping in the paper manufacturing sector. For a short interval of time, this process involves the use of chemicals, such as Na_2CO_3 (6 to 8% solution) or a combination of Na_2CO_3 (50 to 85% solution) and NaOH (15 to 50% solution), as well as high temperatures and high steam pressures (Jiménez *et al*., 2005).

Advantages of soda pulping include reduced cooking time, pulp free of sulfates and good chemical recovery. Anthraquinone can be added to pulp to improve the strength and quality of the paper (Jiménez *et al*., 2009).

Conclusions and Recommendations

Non-wood pulp technology and raw materials may soon gain prominence in the paper manufacturing sector because of the imported pulp huge cost and wood resources scarcity in emerging nations like Pakistan. The heavy reliance of pulp and paper sector on wood causes serious environmental problems such greenhouse gas emissions, deforestation, global warming and the loss of fibrous wood resources. Because of these issues, the paper-based sectors in developing countries now depend heavily on other raw materials. Due to environmental and economic concerns, the pulping of agricultural leftovers has attracted increasing interest. Numerous conclusions have been drawn over time from extensive research and investigations in the subject of pulping of non-wood. As such, worries regarding non-wood fibers utilization in the manufacturing of paper have decreased in comparison to prior years. However, there are still a lot of issues facing the non-wood paper sector.

Pakistan has an abundance of agricultural residue, with wheat accounting for the most (45.88 MT), followed annually by sugarcane bagasse (32.44 MT), rice (17.54 MT) and maize (13.11 MT). As a result, Pakistan has access to enough high-quality non-wood raw materials for pulping. Furthermore, the widespread availability of straws makes it a cheap and appealing raw material for papermaking in Pakistan.

Combining non-wood materials with other wood pulps has the potential to produce pulp of a higher quality while also protecting Pakistan forests and financial resources.

Acknowledgment

I would like to express my sincere gratitude to Director Forest Products Research Division, Pakistan Forest Institute Peshawar and the coauthors for their guidance, assistance and contribution provided throughout this study.

Novelty Statement

This study presents a novel approach to producing pulp and paper in Pakistan by using non-wood fibers, such as agricultural leftovers. It provides a sustainable substitute that might drastically cut down on deforestation and other negative environmental effects while also bringing down manufacturing costs.

Author's Contribution

Abdur Rehman: Contributed in Collection of data of review manuscript and composition of it. Handled the visualization of data and results.
Mansoor Ali Khan: Contributed in composition of review manuscripts and paraphrasing the literature data.
Abdur Rahman Khan: Contributed in reviewing and editing the manuscript to refine its clarity and accuracy.
Sajid Ali: Contributed in collecting and tabulating the data and proof reading of review manuscript.
Zeeshan Ahmad: Contributed to the conceptualization of the study and the development of the research methodology. Also contributed to the critical review and editing of the manuscript.

Conflict of interest
The authors have declared no conflict of interest.

References

Adel, A.M., El-Gendy, A.A., Diab, M.A., Abou-Zeid, R.E., El-Zawawy, W.K. and Dufresne, A., 2016. Microfibrillated cellulose from agricultural residues. Part I: Papermaking application. Ind. Crops Prod., 93: 161-174. https://doi.org/10.1016/j.indcrop.2016.04.043

Agnihotri, S., Dutt, D. and Tyagi, C.H., 2010. Complete characterization of bagasse of early species of Saccharum officinerum-Co 89003 for pulp and paper making. BioResources, 5(2): 1197-1214. https://doi.org/10.15376/biores.5.2.1197-1214

Ashori, A., 2006. Nonwood fibers. A potential source of raw material in papermaking. Polymer. Plast. Technol. Eng., 45(10): 1133-1136. https://doi.org/10.1080/03602550600728976

Ashrafi, O., Yerushalmi, L. and Haghighat, F., 2015. Wastewater treatment in the pulp-and-paper industry: A review of treatment processes and the associated greenhouse gas emission. J. Environ. Manage., 158: 146-157. https://doi.org/10.1016/j.jenvman.2015.05.010

Atchison, J.E., 1993. Making the right choices for successful bagasse newsprint production: Part 2. Tappi J. (United States), 76(1).

Ateş, S., Deniz, I., Kirci, H., Atik, C. and Okan, O.T., 2015. Comparison of pulping and bleaching behaviors of some agricultural residues. Turk. J. Agric. For., 39(1): 144-153. https://doi.org/10.3906/tar-1403-41

Bhardwaj, N.K., Kaur, D., Chaudhry, S., Sharma, M. and Arya, S., 2019. Approaches for converting sugarcane trash, a promising agro residue, into pulp and paper using soda pulping and elemental chlorine-free bleaching. J. Clean. Prod., 217: 225-233. https://doi.org/10.1016/j.jclepro.2019.01.223

Cappelletto, P., Mongardini, F., Barberi, B., Sannibale, M., Brizzi, M. and Pignatelli, V., 2000. Papermaking pulps from the fibrous fraction of Miscanthus x Giganteus. Ind. Crops Prod., 11(2-3): 205-210. https://doi.org/10.1016/S0926-6690(99)00051-5

Daud, Z., Hatta, M., Zainuri, M., Latiff, A., Aziz, A. and Halizah, A., 2016. Corn stalk fiber material by chemical pulping process for pulp and paper industry. Adv. Mater. Res., 1133: 608-611. https://doi.org/10.4028/www.scientific.net/AMR.1133.608

Deniz, I., Kırcı, H. and Ates, S., 2004. Optimisation of wheat straw Triticum drum kraft pulping. Ind. Crops Prod., 19(3): 237-243. https://doi.org/10.1016/j.indcrop.2003.10.011

Ekhuemelo, D.O. and Tor, K., 2013. Assessment of fibre characteristics and suitability of maize husk and stalk for pulp and paper production. J.

Res. For. Wildl. Environ., 5(1): 41-49.

El-Sakhawy, M., Lönnberg, B., Fahmy, Y. and Ibrahim, A.A., 1996. Organosolv pulping. 3. Ethanol pulping of wheat straw. Cellul. Chem. Technol., 30(1-2): 161-174.

El-Sakhawy, M., Nashy, El-Shahat, H.A., El-Gendy, A. and Kamel, S., 2018. Thermal and natural aging of bagasse paper sheets coated with gelatin. Nordic Pulp Pap. Res. J., 33(2): 327-335. https://doi.org/10.1515/npprj-2018-3033

Enayati, A.A., Hamzeh, Y., Ahmad, M.S. and Molaii, M., 2009. Papermaking potential of canola stalks. BioResources, 4(1). https://doi.org/10.15376/biores.4.1.245-256

Fearon, O., Kuitunen, S., Ruuttunen, K., Alopaeus, V. and Vuorinen, T., 2020. Detailed modeling of kraft pulping chemistry. Delig. Ind. Eng. Chem. Res., 59(29): 12977-12985. https://doi.org/10.1021/acs.iecr.0c02110

Ferdous, T., Ni, Y., Quaiyyum, M.A., Uddin, M.N., and Jahan, M.S., 2021. Non-wood fibers: relationships of fiber properties with pulp properties. ACS Omega, 6(33): 21613-21622. https://doi.org/10.1021/acsomega.1c02933

Garay, R.M.M., Rallo, M.B., Carmona, R.C. and Araya, J.C., 2009. Characterization of anatomical, chemical, and biodegradable properties of fibers from corn, wheat, and rice residues. Chilean J. Agric. Res., 69(3): 406-415. https://doi.org/10.4067/S0718-58392009000300014

Gharehkhani, S., Yarmand, H., Goodarzi, M.S., Shirazi, S.F.S., Amiri, A.Z.M., Nashrul, M. and Wongwises, S., 2017. Experimental investigation on rheological, momentum and heat transfer characteristics of flowing fiber crop suspensions. Int. Commun. Heat Mass Trans., 80: 60-69. https://doi.org/10.1016/j.icheatmasstransfer.2016.11.013

Gominho, J., Curt, M.D., Lourenco, A., Fernandez, J. and Pereira, H., 2018. *Cynara cardunculus* L. as a biomass and multi-purpose crop: A review of 30 years of research. Biomass Bioenergy, 109: 257-275. https://doi.org/10.1016/j.biombioe.2018.01.001

Hemmasi, A.H., Samariha, A., Tabei, A., Nemati, M. and Khakifirooz, A., 2011. Study of morphological and chemical composition of fibers from Iranian sugarcane bagasse. Am. Eurasian J. Agric. Environ. Sci., 11(4): 478-481.

Hurter, A.M., 1988. Utilization of annual plants and agricultural residues for the production of pulp and paper. Paper presented at the Pulping Conference:[proceedings](USA).

Hurter, R.W. and Eng, P., 2002. Strategic market management system pulp and paper. Hurter Consult Incorporated, pp. 48.

Jiménez, L., Pérez, A., de la Torre, M.J., Moral, A. and Serrano, L., 2007. Characterization of vine shoots, cotton stalks, *Leucaena leucocephala* and *Chamaecytisus proliferus*, and of their ethyleneglycol pulps. Bioresour. Technol., 98(18): 3487-3490. https://doi.org/10.1016/j.biortech.2006.11.009

Jiménez, L., Ramos, E., Rodrıguez, A., De la Torre, M.J. and Ferrer, J.L., 2005. Optimization of pulping conditions of abaca. An alternative raw material for producing cellulose pulp. Bioresour. Technol., 96(9): 977-983. https://doi.org/10.1016/j.biortech.2004.09.016

Jiménez, L., Serrano, L., Rodríguez, A. and Sánchez, R., 2009. Soda-anthraquinone pulping of palm oil empty fruit bunches and beating of the resulting pulp. Bioresour. Technol., 100(3): 1262-1267. https://doi.org/10.1016/j.biortech.2008.08.013

Johnson, P., 1999. Industrial hemp: A critical review of claimed potentials for *Cannabis sativa*. Tappi J., 82(7): 113-123.

Kaur, D., Bhardwaj, N.K. and Lohchab, R.K., 2018. A study on pulping of rice straw and impact of incorporation of chlorine dioxide during bleaching on pulp properties and effluents characteristics. J. Clean. Prod., 170: 174-182. https://doi.org/10.1016/j.jclepro.2017.09.111

Khalil, H.A., 2011. Vermicomposting of different types of oil palm fibre waste using Eudrilus eugeniae: A comparative study. J. Oil Palm Res., 23: 979-989.

Khristova, P., Kordsachia, O., Patt, R., Karar, I. and Khider, T., 2006. Environmentally friendly pulping and bleaching of bagasse. Ind. Crops Prod., 23(2): 131-139. https://doi.org/10.1016/j.indcrop.2005.05.002

Kiaei, M., Samariha, A. and Kasmani, J.E., 2010. Characterization of biometry and chemical and morphological properties of fibers from bagasse, corn, sunflower, rice, and rapeseed residues in Iran. J. For. Environ. Sci., 26(2): 75-82.

Kong, H., He, J., Wu, H., Wu, H. and Gao, Y., 2012. Phenanthrene removal from aqueous solution on sesame stalk-based carbon. Clean

Soil, Air, Water, 40(7): 752-759. https://doi.org/10.1002/clen.201100322

Laftah, W.A. and Rahman, W.A., 2016. Pulping process and the potential of using non-wood pineapple leaves fiber for pulp and paper production: A review. J. Natl. Fibers, 13(1): 85-102. https://doi.org/10.1080/15440478.2014.984060

Latta, G.S., Plantinga, A.J. and Sloggy, M.R., 2016. The effects of internet use on global demand for paper products. J. For., 114(4): 433-440. https://doi.org/10.5849/jof.15-096

Madakadze, I.C., Masamvu, T.M., Radiotis, T., Li, J. and Smith, D.L., 2010. Evaluation of pulp and paper making characteristics of elephant grass (*Pennisetum purpureum* Schum) and switchgrass (*Panicum virgatum* L.). Afr. J. Environ. Sci. Technol., 4(7): 465-470.

Main, N.M., Talib, R.A., Ibrahim, R., Rahman, R.A. and Mohamed, A.Z., 2014. Suitability of coir fibers as pulp and paper. Agric. Agric. Sci. Proced., 2: 304-311. https://doi.org/10.1016/j.aaspro.2014.11.043

Moore, G., 1996. Nonwood fibre applications in papermaking: A literature review: Pira International.

Mossello, A.A., Harun, J., Shamsi, S.R.F., Resalati, H., Tahir, P.M., Rushdan, I. and Mohmamed, A.Z., 2010. A review of literatures related to kenaf as a alternative for pulpwoods. Agric. J., 5(3): 131-138. https://doi.org/10.3923/aj.2010.131.138

Mousavi, S.M.M., Hosseini, S.Z., Resalati, H., Mahdavi, S. and Garmaroody, E.R., 2013. Papermaking potential of rapeseed straw, a new agricultural-based fiber source. J. Clean. Prod., 52: 420-424. https://doi.org/10.1016/j.jclepro.2013.02.016

Ogunsile, B.O. and Oladeji, T.G., 2016. Utilization of banana stalk fiber as reinforcement in low density polyethylene composite. Matéria (Rio de Janeiro), 21: 953-963. https://doi.org/10.1590/s1517-707620160004.0088

Oinonen, H. and Koskivirta, M., 1999. Special challenges of pulp and paper industry in Asian populated countries, like Indian sub-continent and China. Proc. Paperex, pp. 49-68.

Peng, F. and Sirnonson, R., 1991. High-yield chemimechanical pulping of bagasse: Part 3. Bagasse chemimechanical pulp with alkaline sulfite pretreatment. Nordic Pulp Paper Res. J., 6(4): 170-176a. https://doi.org/10.3183/npprj-1991-06-04-p170-176

Possible usses of crop residue for energy generation instead of open burning, 2019. SAARC Energy Centre. pp. 137.

Rezayati-Charani, P., Mohammadi-Rovshandeh, J., Hashemi, S.J. and Kazemi-Najafi, S., 2006. Influence of dimethyl formamide pulping of bagasse on pulp properties. Bioresour. Technol., 97(18): 2435-2442. https://doi.org/10.1016/j.biortech.2005.08.026

Rosa, M.R., Rocha, G.J.M. and Curvelo, A.A.S., 1999. Organosolv delignification of steam exploded wheat straw. RECEN-Rev. Ciências Exat. Natur., 1(1): 49-55.

Rowell, R.M. and Cook, C., 1998. Types and amounts of nonwood fibers available in the US. Paper presented at the Proceedings, 1998 North American Nonwood Fiber Symposium (Atlanta).

Rudi, H., Resalati, H., Eshkiki, R.B. and Kermanian, H., 2016. Sunflower stalk neutral sulfite semi-chemical pulp: an alternative fiber source for production of fluting paper. J. Clean. Prod., 127: 562-566. https://doi.org/10.1016/j.jclepro.2016.04.049

Saijonkari-Pahkala, K., 2001. Non-wood plants as raw material for pulp and paper. https://doi.org/10.23986/afsci.5707

Samariha, A. and Khakifirooz, A., 2011. Application of NSSC pulping to sugarcane bagasse. BioResources, 6(3). https://doi.org/10.15376/biores.6.3.3313-3323

Sandberg, C., Hill, J. and Jackson, M., 2020. On the development of the refiner mechanical pulping process–A review. Nordic Pulp Paper Res. J., 35(1): 1-17. https://doi.org/10.1515/npprj-2019-0083

Sridach, W., 2010. The environmentally benign pulping process of non-wood fibers. Suranaree J. Sci. Technol., 17(2).

Thiruchitrambalam, M., Alavudeen, A. Venkateshwaran, N., 2012. Review on kenaf fiber composites. Rev. Adv. Mater. Sci., 32(2): 106-112.

Tian, H., Lu, Q., Gopaluni, R.B., Zavala, V.M. and Olson, J.A., 2019. An economic model predictive control framework for mechanical pulping processes. Contr. Eng. Pract., 85: 100-109. https://doi.org/10.1016/j.conengprac.2019.01.008

Tofanica, B.M., Cappelletto, E., Gavrilescu, D. and Mueller, K., 2011. Properties of rapeseed (*Brassica napus*) stalks fibers. J. Natl. Fibers, 8(4): 241-262. https://doi.org/10.1080/15440478.2011.626189

Tsalagkas, D., Börcsök, Z., Pásztory, Z., Gryc, V., Csóka, L. and Giagli, K., 2021. A comparative fiber morphological analysis of major agricultural residues (used or investigated) as feedstock in the pulp and paper industry. BioResources, 16(4): 7935. https://doi.org/10.15376/biores.16.4.7935-7952

van Dam, J.E.G., van den Oever, M.J.A., Keijsers, E.R.P., van der Putten, J.C., Anayron, C., Josol, F. and Peralta, A., 2006. Process for production of high density/high performance binderless boards from whole coconut husk. 2. Coconut husk morphology, composition and properties. https://doi.org/10.1016/j.indcrop.2005.03.003

Ververis, C., Georghiou, K., Christodoulakis, N., Santas, P. and Santas, R., 2004. Fiber dimensions, lignin and cellulose content of various plant materials and their suitability for paper production. Ind. Crops Prod., 19(3): 245-254. https://doi.org/10.1016/j.indcrop.2003.10.006

Yadav, K.K., Patil, P.B., Kumaraswamy, H.H. and Kashyap, B.K., 2020. Ligninolytic microbes and their role in effluent management of pulp and paper industry. Waste to energy: Prospects and applications, pp. 309-350. https://doi.org/10.1007/978-981-33-4347-4_13

Young, R.A., 1997. Processing of agro-based resources into pulp and paper. Paper and composites from agro-based resources. Eds. Rowell, RM, Young, RA, Rowell, JK CRC Lewis Publishers, Boca Raton, FL, pp. 137-245.

Yousefi, H., 2009. Canola straw as a bio-waste resource for medium density fiberboard (MDF) manufacture. Waste Manage., 29(10): 2644-2648. https://doi.org/10.1016/j.wasman.2009.06.018