

Rice Straw as a Textile Resource: Circular Economy Perspectives and Socio-economic Potential

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Abstract - The increasing need for sustainable materials is due to the large quantity of agricultural waste generated, along with worries about the environmental effect of conventional textile production. Rice straw is one of the major agricultural residues, resulting from rice production, which has great potential for added-value uses the development of sustainable materials and the management of agricultural residues could be connected through the use of rice straw in Textile products. This paper will discuss the potential applications of rice straw in the textile sector from the perspectives of resource vaporization, environmental sustainability, the circular economy, and socioeconomic development. The low-value residue known as rice straw will be transformed into an intermediate product using a cycle model, which will also facilitate the development of relationships between farmers, rural businesses, and the textile industry. However, there are certain issues with gathering, shipping, seasonality, material variety, processing, standardization, and market acceptance. The authors stress the fact that development of the system which makes use of rice straw in textile production demands multidisciplinary studies, life cycle assessment and techno economic assessments.

Keywords: Rice straw, textile source, circular economy, agricultural residue, sustainable fabrics, resource utilization, rural development, socio-economic potential

1.INTRODUCTION

The increased generation of agriculture residues has led to environmental concerns and sustainable use of the resources at the same time. Rice straw is one of the most common crop residues, especially in Asian countries growing rice (Alengebawy et al., 2023). After harvesting of rice, plenty of rice straw remains in the field. In situations where there is no system to collect and utilize the residue, it can be burned due to time and economic constraints (Gupta et al., 2004; Kaur et al., 2022). Rice straw burning in India has been connected to air pollution, greenhouse gases emission, nutrient loss and economic loss. In a recent review, it was found that the In a recent review, it was found that India produces 136 million tonnes of rice per annum, whereas worldwide production is 572

million tonnes (Singh et al., 2023). The corresponding rice straw generation is substantial: global annual rice straw production is estimated at about 731 million tonnes, of which India contributes approximately 126.6 million tonnes, and around 60% of it is burnt in the field, with attendant environmental and economic impacts (Bhattacharyya et al., 2021). Rice straw is a lignocellulosic biomass mainly comprising cellulose, hemicellulose, and lignin, along with ash, silica, and other minor components (Aggarwal et al., 2021; Bhattacharyya et al., 2019). This composition makes it possible to convert it into many valuable products (Singh et al., 2023). There has been an increasing trend towards integrated biorefineries, where different fractions of rice straw can be used for different products in a cascading, circular-bioeconomy approach (Illankoon et al., 2023; Le et al., 2021). The textiles industry could aid in this process by looking into the use of rice straw as a sustainable resource in textile-compatible form, since long natural cellulose fibers extracted from rice straw show properties similar to linen fibers (Reddy & Yang, 2006). Such possibilities do not limit themselves to the manufacture of traditional spun yarns (Hattayanant et al., 2017; Ratnakumar et al., 2019). Based on characteristics and processes, rice straw derived resources can also be explored as possible components of textile blends, nonwovens (Ağirgan & Taşkın, 2018), technical textiles and composites (Ratnakumar et al., 2020), and other sustainable textiles, including natural dye and multifunctional finishing applications (Kadam et al., 2019). The aim of this paper is to examine the possibility of using rice straw as a sustainable resource in textiles, especially in relation to circular economy aspects and socio-economic potentials.

2. TEXTILE POTENTIAL OF RICE STRAW

The structure of the rice straw is mainly constituted of a lignocellulosic matrix. The cellulose provides strength, while the hemicellulose and lignin provide organization and strength in the plant cell wall. Moreover, rice straw has significant quantities of inorganic content such as silica and ash. These are the distinguishing factors for the rice straw compared to regular textiles and affect its processing and usage possibilities. The presence of cellulose is what makes rice straw an interesting object of study in terms of material for textiles. Nevertheless, the cellulose is present in a composite matrix, which is why the

properties of the rice straw material are highly dependent on the separation or modification process. The purpose of the process must depend on the ultimate goal, which is the use of the material in either technical or regular textiles.

characteristic	Relevance to textile materials
Cellulose-enriched structure	Potential for cellulose development
Lignocellulosic structure	Potential for renewable structure of biomass
Agricultural renewable source	Potential for bio-based materials development
Mass production	Potential for significant feedstock supply
Availability of lignin and hemicellulose	Influence on processing and properties of materials
Silica and ash	Influence on processing, durability and quality
Composition variation	Needs proper quality control

Table 1-*Rice Straw Features Pertinent to Textile Applications*

Utilization of the textile properties of rice straw relies on aligning its physical properties with an appropriate use. Where the finer textile items would need more processing and controls, the non-woven and technical textile sector could make allowance for a wider variety of physical properties. Mixing rice straw-based cellulose with normal textile fibers could offer another way of introducing agricultural waste using existing processing equipment. Besides, rice straw could find application in the non-woven, agricultural textiles, mats, packaging, insulation and some composite sectors.

3. RICE STRAW FOR A CIRCULAR ECONOMY

The circular economy model aims at minimizing waste, improving efficiency, and keeping resources in productive use for as long as possible. In this regard, the process of rice-straw valorization is consistent with this philosophy, as the resulting waste from food production can be utilized in materials applications.

In a conventional linear system, the pathway is represented as:

Rice cultivation → harvesting → straw generation → disposal

A circular approach can instead follow:

Rice cultivation → straw collection → material vaporization → textile product → use → recovery/recycling

This method offers an opportunity to preserve the value contained within agricultural biomass and generate further economic activities through residue collection and processing. Environmental benefits of rice-straw recycling should nonetheless be estimated over the whole life cycle. The impacts of collection and transport, water consumption, chemicals usage, energy consumption and yield rate might affect the overall environmental benefits. A material therefore cannot be viewed as sustainable simply by virtue of its feedstock being agro-waste. A life cycle assessment will enable estimating if a rice-straw textile product offers any environmental benefits in comparison with conventional products. In recent years, there was growing awareness of the need for the life cycle approach in rice straw vaporization

assessment. The other benefit that can be derived from the recycling approach is cascaded use. Depending on their characteristics, different fractions of rice straw may be used in various applications. Cellulosic fractions can be used in the production of materials, whereas the rest can potentially be used in chemical, biological or energy applications.

4. SOCIO-ECONOMIC PERSPECTIVES FOR RICE STRAW

The process of converting rice straw to textile resources can have socio-economic consequences due to the creation of value at different points along the supply chain process. Currently, rice straw might not have any economic value in regions where there is no system for collecting and using the material. Creating new markets through the use of residue materials can open up economic possibilities. The initial step in this process of creating value chains can involve the process of collecting and aggregating. Collecting can create more economic opportunities for farmers and workers in the rural sector. Other steps like sorting, drying, storage, transportation, and pre-processing can create more employment opportunities. A decentralized system of processing units might become especially significant in the rice growing areas. Having primary processing near the source can help cut down the transport of heavy material and involve more people from the local communities. Also, community enterprises can produce a range of items from rice straw material. These items could include non-woven items, decorations, environmentally friendly packaging, accessories and some technical items. The financial profitability of such enterprise would depend on availability of raw materials, processing technologies, market needs and prices. The socio-economic impact should be spread through

the entire value chain rather than focused only on production stage. The right circular economy model would connect farmers, collecting points, processing units, textile producers and end users.

Economic/Social Aspects	Possible Advantage	Vital concern
Textile sector	Alternative agricultural residue source availability	Consistency of quality and quantity
Small businesses	Opportunities for rural or community-based textile industry	Capital investment and limited technological infrastructure
Market development	Increased interest in sustainable and bio-based products	Consumers' acceptance and competitive pricing
Farmer income	Increased revenue from the sale of rice straw	Uncertainty and volatility of residue prices
Rural employment	Job opportunities related to collection, sorting, storing and processing	Seasonal character of work
Environment-economic gain	Decrease in residue burning along with earning money	Feasibility is dependent on processing and logistics
Rural development	Earning of economic value by agricultural communities	Imbalance of benefit sharing among the stakeholders
Development of value chain	Connections between farmers, processors and textile industry	Unorganized value chain linkages
Collection system	Local rice straw collecting business establishment	Expensive collection and transportation
Market development	Increased interest in sustainable and bio-based products	Consumers' acceptance and competitive pricing

Table 2- Socio-Economic Potential Benefits of Rice Straw Textile Vaporization

5. PROBLEMS AND FUTURE POSSIBILITIES

There are various factors that need to be considered and addressed in order to successfully make rice straw an accepted textile material for commercial purposes. For instance, there is the issue of variability in the feedstock. The physical and chemical composition of the rice straw differs depending on the type of rice and how it is cultivated. Another significant

economic factor includes the collection and transport of the rice straw from one place to another. Due to its bulky nature and the fact that it can be found all over agricultural lands, transporting the material becomes quite difficult. There is the possibility of establishing local processing facilities. Seasonality is yet another factor that has to be considered. This is because rice straw is only produced at certain times of the year whereas textiles have to be produced continuously all year round. Therefore, adequate storage facilities have to be put in place. Another factor that has to be considered is the presence of silica and ash. Futuristic research must target development of efficient and eco-friendly processing technologies. Saving in water usage and chemical consumption, recycling of the processing chemicals, improved energy efficiency and material yield would make the production process of rice-straw-based materials more sustainable. Futuristic research must not limit itself to production of materials in laboratory scale. Textile performance and longevity testing, life cycle assessment, techno-economic evaluation and consumer research should be conducted in order to define the practical applicability of these materials. In other words, the future of rice straw utilization might include application of the material in more than one area. Depending on the characteristics of the material, fine textiles, composite materials, nonwoven textiles and technical textiles can be produced

6. CONCLUSIONS

Rice straw is a renewable agricultural residue that holds promise as a sustainable material for textile applications. Due to its lignocellulosic nature, specifically its cellulose content, there are opportunities for exploring possibilities in bio-based material manufacturing. Potential uses include not only textile materials, but also blends, non-wovens, technical textiles, and bio-based composites. In terms of the circular economy, rice straw could be transformed from being an agricultural residue into a secondary resource, thus enhancing biomass use and increasing material value. Rice straw usage could also offer another avenue away from agricultural residue burning and help develop more efficient production processes. Another aspect of socio-economic importance is that rice straw collection and conversion into material would create opportunities for farmers, rural laborer's, small businesses and textile producers. Economic value, however, will be contingent on efficient logistics, appropriate technology, consistent quality of raw material and market demand. The future development should thus proceed with an integrated strategy combining agriculture, biomass conversion, textile technology, and circular economy considerations. Life cycle assessment and techno-economic evaluation should accompany material development in order to prove rather than assume environmental and economic advantages. With proper

technological, institutional, and market mechanisms in place, rice straw can be made a useful part of circular bio-based textile industry.

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