



ISSN Print: 2664-844X
 ISSN Online: 2664-8458
 NAAS Rating (2026): 4.97
 IJAFS 2026; 8(2): 373-380
www.agriculturaljournals.com
 Received: 08-12-2025
 Accepted: 14-01-2026

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Sustainable product development from rice paddy

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DOI: <https://www.doi.org/10.33545/2664844X.2026.v8.i2e.1206>

Abstract

Rice paddy, a widely cultivated crop globally, generates significant agricultural by-products, including rice husk, straw, and bran. Traditionally regarded as waste, these by-products are often discarded or burned, leading to environmental concerns such as air pollution and resource depletion. Recent advancements in material science have identified the benefits of rice paddy by-products for various product applications. This review paper explores sustainable products by repurposing rice paddy waste, focusing on its environmental advantages and practical uses in product design. Through an analysis of existing literature and case studies, this paper highlights how rice paddy by-products can replace conventional materials like wood and plastics, contributing to waste reduction and resource efficiency. The review also discusses the physical and mechanical properties of rice straw composites, evaluating their durability and cost-effectiveness. In conclusion, this review emphasizes the need for further research to optimize the use of rice paddy by-products and expand their applications across industries. By adopting these sustainable practices, it is possible to foster a circular economy and minimize the environmental impact of conventional manufacturing processes, thus advancing eco-friendly product development.

Keywords: Rice husk, agriculture, by-product, sustainable

Introduction

Rice is a staple food for a significant portion of the global population, cultivated across 150 million hectares with an annual production of approximately 590 million tons. As reported by the Ministry of Agriculture and Farmers' Welfare (2023), in India, rice is a primary dietary component, with major contributions from states such as West Bengal (14 million tons), Uttar Pradesh (12 million tons), Punjab (11 million tons), Haryana (8 million tons), and Chhattisgarh (7 million tons). The rice milling process yields approximately 22% of its weight as rice husk, a by-product that holds substantial potential for industrial applications.

Rice husk (RH), an abundant lignocellulosic material, is generated in rice-producing countries and has emerged as a valuable resource due to its unique chemical and physical properties. Containing approximately 75% organic volatile matter and 25% ash, rice husk is a significant source of amorphous silica (85%-90%). Its high silica content, lightweight structure, high porosity, and absorbent properties make it suitable for diverse industrial applications, including composite materials, thermal insulation, and building materials. The bulk density of rice husk ranges from 86 to 114 kg/m³, and its moisture content varies between 8.68% and 10.44%, contributing to its versatility in both thermochemical and biochemical conversion processes.

India, producing an estimated 120 million tons of rice husk annually, primarily utilizes it as a boiler fuel in rice mills for generating steam during the parboiling process. The utilization of RH as a strengthening agent in building materials addresses the increasing demand for sustainable, cost-effective, and durable alternatives, especially in the construction sector, which faces shortages of traditional materials like bricks, cement, and sand. Globally, research efforts are focused on maximizing the utility of rice husk and its derivatives. Applications of RH include its use as aggregates and fillers for concrete and board production, soil enhancers, insulation materials in steel mills and an economical substitute for microsilica. Despite its broad utility, a significant portion of rice husk remains underutilized, raising environmental concerns due to improper waste management.

The present study aims to explore the potential of rice husk as a sustainable raw material for innovative product development, focusing on its unique properties and broad applicability.

By utilizing the abundant availability of rice husk, this research aims to explore environmental conservation, waste management, and the development of sustainable materials for industrial and construction purposes.

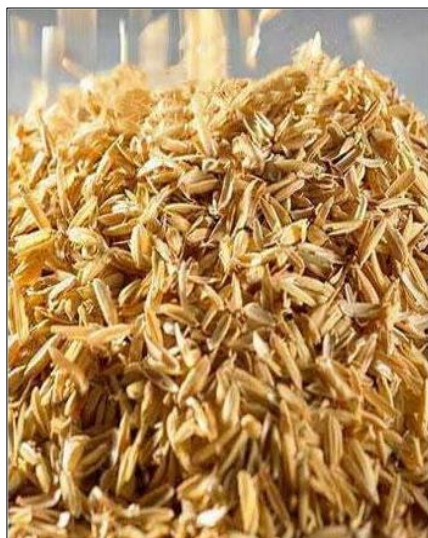


Fig 1: Rice Husk

Materials and Methods

- **Research Design:** The present study was undertaken to explore sustainable product development from rice paddy by-products through a systematic and analytical review of existing literature. The research adopted a descriptive and analytical research design, focusing on the identification, evaluation, and synthesis of scientific studies related to the utilization of rice husk, rice straw, and rice bran in product development.
- **Source of Data:** The study was based on secondary data collected from authentic and reliable sources. Relevant information was obtained from Peer-reviewed national and international journals, Research articles and conference proceedings, Government reports and policy documents, Books and book chapters related to sustainable materials and product design, as well as online academic databases such as Google Scholar, ScienceDirect, Scopus-indexed journals, and ResearchGate. The literature reviewed was primarily published between 2000 and 2025 to ensure contemporary relevance.
- **Selection Criteria for Literature:** The literature was

selected based on the following criteria:

Inclusion Criteria

- Studies focusing on rice paddy by-products (rice husk, rice straw, rice bran)
- Research related to sustainable material development and product applications
- Studies reporting physical, mechanical, thermal, or environmental properties
- Articles published in English

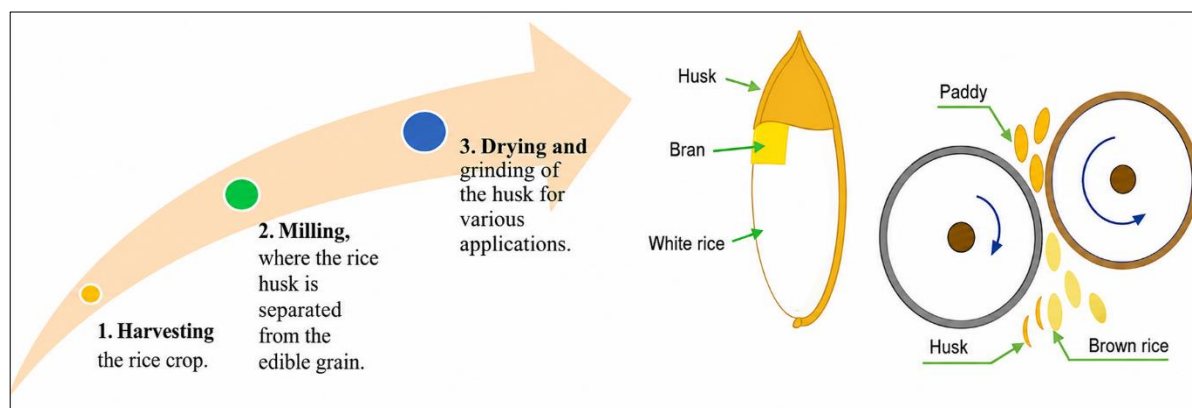
Exclusion Criteria

- Studies not related to product development
- Publications lacking sufficient methodological clarity
- Duplicate or non-peer-reviewed sources

- **Method of Data Collection:** Relevant studies were identified using specific keywords such as “rice husk composites,” “rice straw sustainable products,” “bio-composites from agricultural waste,” and “circular economy and rice waste.” Boolean operators (AND, OR) were used to refine the search results. Selected articles were thoroughly reviewed, and essential data were extracted and tabulated under predefined headings for systematic comparison and interpretation.
- **Method of Data Analysis:** The collected data were analyzed using comparative and thematic analysis techniques. A comparative analysis was conducted to evaluate the performance of rice paddy-based materials in relation to conventional materials such as wood, plastics, and synthetic composites. Thematic categorization was performed to identify major areas of application and sustainability benefits. Findings were synthesized to highlight trends, research gaps, and potential areas for future exploration.
- **Sustainability Assessment Criteria:** The sustainability potential of rice paddy-based products was assessed based on:
 - Waste reduction capability
 - Reduction in carbon emissions
 - Resource efficiency
 - Biodegradability and recyclability
 - Contribution towards circular economy principles

Results

Processing of Rice and Rice Husk: The processing of rice typically involves:



The processing techniques can significantly influence the properties of rice husk and its suitability for different uses. (Korotkova, 2016) ^[7]

Fig 2: Processing of Rice husk

Composition of Rice Husk: The composition of rice husk is:

Table 1: Composition of Rice Husk

Component	Percentage	Key function
Cellulose	28-38%	Provides structural strength.
Hemicellulose	20-30%	Aids in binding and processing.
Lignin	9-20%	Offers rigidity and resistance to decay.
Silica	18-23%	Enhances durability and strength.

The unique composition of rice husk makes it an attractive alternative to traditional materials in various applications. (Korotkova, 2016) ^[7]

Properties of Rice Husk

- **High Silica Content:** Rice husk is characterized by its high silica content, typically ranging between 20% and 25%. Silica plays a vital role in enhancing the mechanical properties of materials by improving strength and durability. This makes rice husk an excellent component for composite materials, ensuring resistance to wear and tear. Additionally, the presence of silica contributes to better thermal stability and reduced moisture absorption, which enhances the lifespan of products made from rice husk composites.
- **Lightweight and Fibrous Nature:** One of the most advantageous properties of rice husk is its lightweight and fibrous structure. Its lightness simplifies handling and processing during manufacturing, making it a convenient raw material. The fibrous nature of rice husk ensures better integration into various material matrices, leading to improved mechanical interlocking between rice husk fibres and other components. This property is beneficial in the production of bio composites, where rice husk can replace synthetic fibre.
- **Thermal Insulation:** Rice husk has excellent thermal insulation properties due to its unique cellular structure. This makes it highly suitable for energy-efficient construction materials such as insulation boards or panels. By incorporating rice husk into building materials, it is possible to enhance energy efficiency, reduce heat transfer, and lower energy costs for heating and cooling in buildings (Korotkova, 2016) ^[7].

Benefits of Rice Husk

- **Environmental Benefits:** The reuse of rice husk can reduce its contribution to landfills and carbon footprint associated with traditional disposal methods such as burning. This practice aligns with the principles of the circular economy, transforming waste into valuable resources. Furthermore, utilizing rice husk aids in reducing greenhouse gas emissions, thereby playing a crucial role in combating climate change.
- **Economic Advantages:** Rice husk offers cost-effective alternatives to traditional raw materials, reducing production costs, boosting rural economies. Its availability in rice-growing regions provides employment opportunities, particularly in rural areas, fostering sustainable community development. The diverse applications of rice husk, including its use in biofuels, biodegradable cutlery, and industrial materials, illustrate its potential to contribute to various economic sectors while promoting sustainability.
- **Agricultural Benefits:** Rice husk acts as a natural soil

conditioner, improving soil aeration, moisture retention, and overall structure. These properties enhance crop yields and contribute to healthier farming practices. When processed into organic fertilizers, rice husk enriches soil with essential nutrients, reducing dependence on chemical fertilizers and supporting sustainable agriculture.

- **Energy Potential:** Rice husk possesses a high calorific value, making it a valuable resource for biofuel production. As a renewable energy source, it can significantly reduce reliance on fossil fuels, contributing to energy sustainability. Its use in local energy production also lowers costs and promotes energy independence in rural communities, offering a sustainable solution to energy needs.
- **Health and Safety:** Products derived from rice husk are generally non-toxic, ensuring their safety for household and industrial use. They provide a sustainable alternative to plastic products, addressing the growing problem of plastic pollution. By replacing single-use plastics with biodegradable rice husk-based products, we can protect ecosystems and promote healthier living environments.

Environmental impact of Rice Husk Waste

- **Air Pollution:** One of the most concerning hazards associated with rice husk waste is air pollution caused by its open burning. When rice husk is burned in open fields, it releases a significant amount of greenhouse gases, including carbon dioxide (CO₂) and methane (CH₄). Additionally, the process emits toxic substances such as carbon monoxide (CO), particulate matter, and other harmful compounds. These emissions contribute to poor air quality, smog formation, and global warming. For individuals exposed to the resulting pollution, especially those in nearby areas, respiratory issues such as asthma, bronchitis, and other lung diseases become a significant concern.
- **Soil and Water Contamination:** Improper disposal of rice husk waste poses a serious threat to soil and water quality. When dumped in open spaces or near water bodies, rice husk can leach silica and other chemicals into the surrounding environment. Over time, the accumulation of silica in soil can alter its composition, reducing fertility and negatively impacting agricultural productivity. Furthermore, when these chemicals seep into water bodies, they can harm aquatic ecosystems by altering water pH and contaminating drinking water sources, affecting both biodiversity and human health.
- **Fire Hazards:** Dry rice husk is highly flammable due to its lightweight and fibrous nature. Large piles of rice husk stored without adequate precautions can become a fire hazard, especially in hot and dry climates or in proximity to ignition sources. Once ignited, these fires can spread rapidly, causing extensive damage to nearby infrastructure, crops, and natural habitats. Managing rice husk waste with proper fire safety measures is crucial to mitigate such risks and ensure community safety. (Kumar, 2013) ^[8].

Sustainable Utility Product Development from Rice husk
Rice Husk Ash (RHA) Concrete: When rice husk (Fig 3) is burned under controlled conditions, it produces rice husk ash, which can be used as an alternative pozzolanic material

in concrete production. RHA improves the strength and durability of concrete while reducing the carbon footprint associated with cement production, which is a major contributor to greenhouse gas emissions. Adding fine (instead of more extensive) RHA particles enhances the flexural, compressive, and tensile strength values and limits the chloride ion penetration with time. An adverse impact was found to increase the water-cement ratio, which is assigned to the effect of water on RHA and as a result on the porosity of the concrete.



Fig 3: Rice Husk Ash Concrete

Insulation Materials

Rice husk, with its natural thermal insulating properties (Fig 4), is an excellent material for improving energy efficiency in buildings. Its fibrous structure traps air, reducing heat transfer and helping maintain stable indoor temperatures. This reduces the need for artificial heating and cooling, leading to lower energy consumption and reduced utility bills. Rice husk-based insulation is eco-friendly, renewable, and biodegradable, offering a sustainable alternative to conventional materials. Additionally, it is cost-effective, especially in regions with abundant rice production, making it an affordable solution for energy-efficient construction. Using rice husk in insulation helps create more sustainable, energy-efficient buildings while enhancing indoor comfort.



Fig 4: Insulation Materials

Biodegradable Tableware and Cutleries

Rice husk tableware is one of the most durable forms of biodegradable cutlery that can withstand temperatures of more than 100 °C without being damaged. This reusable tableware has a smooth glossy covering that is 100% natural and derived from the wax present in rice husks. The entire manufacturing process results in a pure natural extract that is free of toxins and harmful by-products as well. These are strong, smooth, compact and reusable and could be a good substitute for daily usage storage like tiffin boxes etc.

Products such as biodegradable plates, cups, and cutlery (Fig 5) can be made from rice husk. These products are environmentally friendly, decompose naturally, and can replace single-use plastics. Innovative designs utilizing rice husk composites can lead to the creation of biodegradable cutlery items.



Fig 5: Biodegradable Tableware and Cutleries

Toothbrush Handles

Rice husk-based toothbrush handles (Fig 6) are a sustainable alternative to traditional plastic handles. By incorporating rice husk into the composite material, these toothbrush handles offer the benefits of biodegradability, helping reduce the accumulation of plastic waste in landfills and oceans. The production of rice husk composites for toothbrush handles is energy-efficient, making it an eco-friendly solution for everyday oral hygiene products. This innovation contributes to reducing the global scenario on single-use plastics, promoting a cleaner, greener future ^[1].



Fig 6: Rice Husk-based Toothbrush Handles

Rice Husk-based Coasters

Rice husk coasters (Fig 7) are an eco-friendly alternative to conventional coasters. Made from rice husk composites, they are lightweight, durable, and water-resistant, effectively protecting furniture surfaces from heat, moisture, and stains. These coasters provide a sustainable solution by utilizing a natural waste product, reducing the use of synthetic materials. Additionally, rice husk coasters are biodegradable, ensuring that they decompose naturally when discarded, minimizing environmental impact. Their versatility and sustainability make them an ideal choice for those looking to combine practicality with eco-

consciousness in everyday household products. (Uddin, 2017) ^[17].



Fig 7: Rice Husk-based Coasters

Packaging Material

Rice husk can be processed into biodegradable packaging materials, providing a sustainable alternative to plastic. These materials can be used for food packaging, cups, (Fig 8) product wraps, and other consumer goods. Packaging materials made from rice husk are sustainable and compostable, offering a biodegradable alternative to conventional plastic packaging. This shift reduces plastic waste and promotes a circular economy in packaging solutions.



Fig 8: Packaging Material

Paper Board

Rice husk fibres can be effectively used in paperboard (Fig 9) production as an environmentally friendly alternative to traditional wood-based materials. The process begins with collecting and cleaning the husk after rice milling to remove impurities. The husk is then mechanically processed, usually by grinding or shredding, to break it down into smaller particles.

The next step is pulping, where the ground husk is mixed with water and chemicals (or treated with steam and pressure in an eco-friendlier process) to separate the cellulose fibres. After pulping, the mixture is dried and pressed into sheets of paperboard, which can be cut and shaped for various uses. Utilizing rice husk in paperboard manufacturing reduces the need for wood, helping conserve forests and promote sustainable forestry practices.

Moreover, rice husk-based paper products tend to be lighter and stronger than traditional wood paper, providing advantages in transportation and durability. This approach not only helps reduce waste but also supports the transition to more sustainable and eco-conscious paper production methods. (Khadoo, 2015) ^[6].



Fig 9: Paper Board

Particle Board Partition and Panelling

Rice husk is an ideal raw material for producing particle boards (Fig 10), widely used in furniture and construction, including partition walls and wall panelling. The process starts with cleaning and drying the husk to remove impurities and moisture, ensuring strength in the final product. The dried husk is mixed with adhesives like urea-formaldehyde or phenolic resin, depending on the application. The mixture is then pressed under heat and pressure to form durable particle boards. These boards offer sustainability, excellent thermal and acoustic insulation, and are lightweight yet strong, making them ideal for furniture and interior design. Using rice husk reduces waste and reliance on wood, contributing to environmental conservation. Additionally, the boards improve energy efficiency in buildings and add aesthetic value with their natural look. (Ciannamea, *et al*, 2017) ^[3].



Fig 10: Particle Board

Rice husk Furniture

Rice husk, due to its lightweight, high strength and natural insulation properties make it an ideal choice for a range of furniture items (Fig 11), including chairs, tables, cabinets,

storage units, benches, sofas, shelving units, and decorative pieces. The manufacturing process involves collecting and cleaning the husk, drying it to reduce moisture, producing particle boards by mixing the husk with adhesives, shaping and cutting the boards, and finishing the products with eco-friendly coatings. The final furniture pieces offer various benefits, including sustainability, durability, aesthetic appeal, lightweight design, and natural thermal insulation. Rice husk provides functional and stylish solutions for modern living spaces.



Fig 11: Rice husk Furniture

Ceiling Boards

Rice husk can be creatively transformed into ceiling boards (Fig 12) by mixing it with adhesives and compressing the mixture into sheets, which are then cured. These rice husk-based ceiling boards offer several benefits, including excellent insulation properties and aesthetic appeal. By incorporating rice husk into ceiling board production, the material contributes to sustainable architectural design while providing an eco-friendly solution to traditional ceiling materials. The resulting boards not only enhance energy efficiency by reducing heat transfer but also add a natural and visually appealing element to interior spaces.



Fig 12: Ceiling Boards

Rice Husk-based Lighting Fixtures

Rice husk composites can be used to create eco-friendly lighting fixtures (Fig 13), including lampshades and lamp bases. These products provide a natural, rustic aesthetic, offering a sustainable alternative to traditional lighting components. By incorporating rice husk into the design, these fixtures help reduce the environmental impact of conventional materials, promoting a more sustainable

approach to interior lighting. The use of rice husk composites in lighting also contributes to waste reduction and the creation of unique, environmentally friendly products for modern spaces.



Fig 13: Lighting Fixtures

Rice Husk Floor Tiles

Rice husk-based composite tiles (Fig 14) offer an eco-friendly alternative to traditional ceramic or vinyl flooring. These tiles are durable, non-toxic, and sustainable, reducing the environmental impact of flooring production. Their durability ensures long-lasting performance, while their non-toxic properties make them a safer choice for indoor environments, promoting both environmental and human health. (Abeid, 2019)^[1].



Fig 14: Floor Tiles

Discussion

The present review highlights the significant potential of rice husk as a sustainable raw material for utility product development. The findings indicate that the method of processing rice and its by-products plays a critical role in determining the quality and applicability of rice husk in various industries. Proper drying, grinding, and controlled combustion processes enhance the functional properties of rice husk, particularly its silica reactivity and bonding capacity in composite formulations (Korotkova, 2016)^[7]. Thus, scientific processing techniques are essential to maximize its performance and usability.

The compositional characteristics of rice husk further strengthen its suitability as an alternative material. Its balanced proportion of cellulose, hemicellulose, lignin, and notably high silica content provides structural strength, rigidity, durability, and resistance to moisture and decay. Compared to many other agricultural residues, the high silica percentage gives rice husk an added advantage in

improving mechanical strength and thermal stability, making it a viable substitute for wood-based and synthetic materials in composite production.

In addition to its composition, the physical properties of rice husk—such as its lightweight and fibrous nature—support its integration into bio-composites and construction materials. Its natural thermal insulation capacity enhances its value in energy-efficient building components. Studies on rice husk ash (RHA) demonstrate that its incorporation in concrete improves compressive, tensile, and flexural strength while simultaneously reducing cement consumption and associated carbon emissions. However, parameters such as particle size and water-cement ratio must be optimized to achieve the desired performance.

The environmental dimension of rice husk management presents both challenges and opportunities. Improper disposal methods, particularly open-field burning, contribute to air pollution, greenhouse gas emissions, soil degradation, and fire hazards (Kumar, 2013) ^[8]. Conversely, its conversion into sustainable products such as biodegradable cutlery, packaging materials, particle boards, insulation panels, and furniture demonstrates how agricultural waste can be transformed into value-added resources. Such utilization aligns with circular economy principles by reducing waste and minimizing dependence on non-renewable materials.

Economically, rice husk offers a cost-effective and locally available raw material, particularly in rice-producing regions. Its utilization can generate rural employment, promote small-scale industries, and contribute to sustainable community development. Furthermore, its potential as a renewable energy source enhances energy security and reduces reliance on fossil fuels. The non-toxic and biodegradable nature of rice husk-based products also supports public health and environmental safety by offering alternatives to conventional plastics.

Overall, the findings emphasize that rice husk holds considerable promise for sustainable product innovation. Nevertheless, large-scale implementation requires improved standardization of processing techniques, enhanced material optimization, and comprehensive life-cycle assessments to ensure long-term environmental and economic viability. Continued research and technological advancements will be crucial in expanding its applications and strengthening its role in sustainable development.

Conclusion

The exploration of rice husk as a valuable resource demonstrates its significant potential for sustainable utility product development. With global rice production surpassing 590 million tons, and India being one of the largest producers, a considerable amount of rice husk is generated each year—yet much of it remains underutilized. This literature review emphasized the beneficial properties of rice husk, such as its high silica content, fibrous texture, lightweight nature, and thermal insulation properties, making it a versatile material for diverse applications.

Through various processing methods, rice husk can be converted into a wide range of innovative and sustainable products, including paperboard, particle boards, partition walls, and biodegradable cutlery. These alternatives not only reduce environmental impact by decreasing use of wood and petroleum-based materials but also highlight rice husk's

potential to replace conventional resources in everyday items like packaging materials, table mats, and straws.

Incorporating rice husk into product development promotes waste reduction and sustainable management of agricultural byproducts.

Repurposing rice husk aligns with global sustainability goals by advancing eco-friendly practices, minimizing waste, and promoting local industries. The findings of this review focus on the importance of further research and innovation in finding the potential of rice husk, ultimately paving the way for a more sustainable and responsible approach to product development.

Acknowledgement

The author sincerely acknowledges the valuable contributions of researchers and scholars whose published work formed the foundation of this review study.

Gratitude is extended to the Faculty of Family and Community Sciences, The Maharaja Sayajirao University of Baroda, Gujarat, for academic support. Appreciation is also expressed to various institutions and organizations that have made research literature accessible. Finally, heartfelt thanks are conveyed to family and well-wishers for their constant encouragement and support.

Future Scope of Research on Rice Husk-based Products

The future scope of research on rice husk-based products holds immense promise for innovation and sustainability across various sectors. Some key areas where research can make significant contributions include:

1. **Microwave Utensils:** Research on developing microwave-safe utensils from rice husk composites can explore their thermal stability, durability, and safety. By enhancing their structural properties, researchers can create eco-friendly alternatives to conventional plastic and ceramic microwave utensils, offering both sustainability and functionality.
2. **Wire Insulation Covers:** Rice husk-based materials can be investigated for their potential to be used in wire insulation. With its fibrous nature and thermal resistance, rice husk can offer a sustainable, cost-effective alternative to traditional petroleum-based insulation materials, contributing to energy efficiency and reducing environmental impact in the electronics industry.
3. **Window Blinds:** Exploring the use of rice husk in the manufacturing of window blinds can lead to the development of lightweight, durable, and eco-friendly alternatives to conventional materials. Rice husk composites can provide excellent insulation properties, improving energy efficiency in buildings while reducing reliance on non-renewable materials.
4. **Table Runners & Mats:** Rice husk can be utilized in the production of biodegradable and sustainable table runners and mats. By leveraging its fibrous structure, rice husk composites can offer durability, texture, and aesthetics, making them a sustainable and eco-friendly option for home decor while reducing plastic waste.

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