Paddy By-products Utilization: Industrial and Food Applications

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Introduction

Paddy, the primary form of rice harvested from fields, is one of the most widely grown crops globally. It plays a significant role in ensuring food security, especially in countries like India, China, and Southeast Asia. With global rice production exceeding 510 million metric tons annually, significant volumes of by-products such as rice husk, bran, straw, and broken rice are generated. Traditionally viewed as waste, these by-products have immense potential to be repurposed into value-added products, aligning with sustainable agriculture goals. Harnessing these by-products presents an opportunity to enhance sustainability, reduce waste, and create valuable products for diverse industries, including food, feed, and non-food sectors.

For instance, converting rice husk into energy and rice bran into nutraceuticals can lead to greater profitability for millers and enhanced livelihoods for farmers. Current estimates suggest that effective utilization of rice by-products can add up to 30% more value to the rice industry. Paddy, the harvested rice with its husk intact, contains various components that offer significant value beyond their primary use (Mohidem *et al*., 2022). Each part—husk, bran, broken rice, and straw—serves as a critical raw material for diverse industrial, nutritional, and environmental applications (Goodman, 2020).

Valuable Parts of Paddy

Rice Husk

Rice husk, making up about 20% of paddy weight, is rich in silica (20-25%) and lignin, making it useful in construction materials like concrete additives and insulation boards. It is also converted into rice husk ash (RHA) for the cement and refractory industries (Tan and Norhaizan, 2020; Hossain et al., 2018).

Rice Bran

Rice bran, comprising 8-10% of paddy weight, is rich in lipids, proteins, fiber, vitamins, and antioxidants like gamma-oryzanol. It is used to produce rice bran oil, a heart-healthy oil with cholesterol-lowering properties. Stabilization techniques have expanded its use in nutraceuticals and fortified foods (Borade et al., 2024).

Broken Rice: Broken rice, 10-15% of milled rice, is often undervalued but has wide applications. It is processed into gluten-free rice flour for baked goods, snacks, and noodles. It also serves as a substrate for starch extraction in pharmaceuticals and textiles, and its protein content makes it useful for animal feed and bioethanol production.

Rice Straw

Rice straw, making up 50% of rice plant biomass, exceeds 730 million tons annually. Traditionally burned, it contributes to pollution but is now used in bioenergy, paper, bio-composites, and packaging materials due to its high lignocellulosic content (Jagtap et al., 2024).

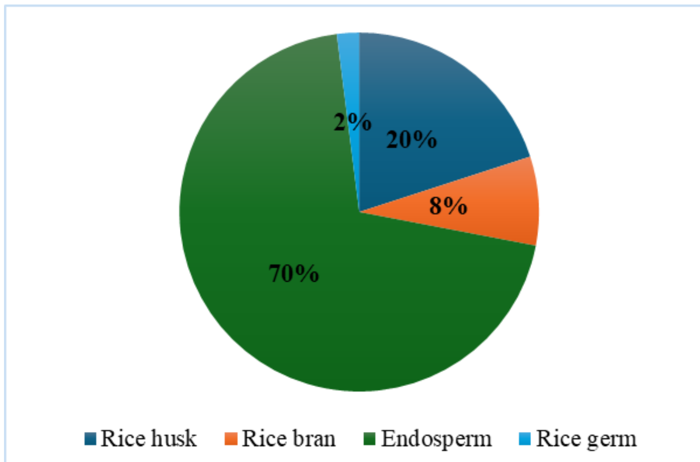

Fig. 1. Composition of paddy grain

By understanding the composition and value of paddy components (Fig. 1), stakeholders in the agriculture and food industries can unlock opportunities for economic growth and environmental sustainability through effective by-product utilization.

Applications of Paddy By-products

Paddy by-products are valuable resources with diverse applications in food, feed, industry, and the environment. Utilizing these by-products fosters innovation, sustainability, and profitability. Below is an overview of their various uses.

Food Applications

Paddy by-products have found significant roles in food processing and product development (Fig. 2.).

Rice Bran in Nutritional Foods: Stabilized rice bran is a key ingredient in fortified cereals, energy bars, and gluten-free baking mixes. Its antioxidant-rich profile is being tapped to create health supplements aimed at managing cholesterol and promoting cardiovascular health (Amanullah *et al*., 2024).

Broken Rice in Gluten-Free Products: The rise in demand for gluten-free diets has positioned broken rice as a prime candidate for producing rice flour, used in bakery items like bread, cakes, and biscuits. It is also transformed into instant rice noodles, porridge, and baby food.

Rice Husk Ash in Food Filtration: Silica extracted from rice husk ash is utilized in the food and beverage industry as a filtration aid, ensuring clarity in beverages like beer and fruit juices.

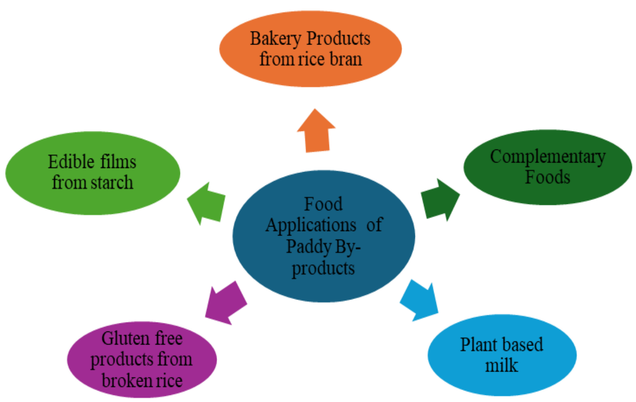

Fig. 2. Food Application of Paddy By-products

Feed Applications

Rice by-products, rich in protein, energy, and fiber, offer a sustainable and cost-effective alternative to conventional feed for livestock, poultry, and aquaculture.

Rice Bran as Animal Feed

Rice bran (12-15% protein, 18-22% lipids) supports growth in poultry, cattle, and swine. Stabilized rice bran prevents rancidity, commonly used in feed formulations in rice-producing countries like India, China, and Thailand.

Broken Rice in Aquaculture Feed

Broken rice, a digestible carbohydrate for fish like carp and tilapia, improves growth and feed conversion. Used at 20-30%, it reduces feed costs by up to 15% while maintaining growth performance.

Rice Straw as Fodder for Ruminants

Rice straw, a valuable roughage for ruminants, benefits from treatments like urea enrichment and enzyme supplementation, improving digestibility and allowing it to replace up to 50% of conventional fodder.

Non-Food Applications

Paddy by-products have diverse applications in industries beyond food and feed, transforming them from agricultural residues into valuable industrial resources. By harnessing their unique properties, industries can develop cost-effective, sustainable alternatives to traditional materials, contributing to circular economies and reducing environmental footprints.

Rice Husk in Construction Materials

Rice husk, comprising about 20% of paddy weight and rich in silica (20–25%), has various construction applications. It is used in lightweight bricks and roof tiles for thermally efficient, affordable housing, as well as in cement additives to enhance strength, durability, and eco-friendliness by reducing carbon footprints. Additionally, rice husk is utilized in geopolymer concrete, a sustainable alternative to Portland cement for infrastructure projects.

Rice Straw in the Paper Industry

Rice straw, with 50% cellulose, is an eco-friendly alternative to wood pulp in paper manufacturing and biodegradable packaging. It supports sustainable paper production and is used in biodegradable food packaging and disposable tableware, reducing plastic reliance.

Bioenergy from Paddy By-products

Rice husk and straw have significant energy potential, especially in rice-producing regions. Rice husk, with high calorific value, fuels boilers for steam and electricity. Rice straw is used in biogas plants for cooking, heating, and power. Pyrolysis of husk and straw creates biochar, improving soil fertility and aiding carbon sequestration.

Nutraceuticals

The nutritional and bioactive components of rice by-products, particularly rice bran, have gained significant attention in the nutraceutical industry. These components provide health benefits beyond basic nutrition, making rice by-products a valuable resource for creating functional foods and dietary supplements. Their role in addressing lifestyle diseases and promoting overall health has driven their incorporation into a growing number of products.

Gamma-Oryzanol from Rice Bran

Gamma-oryzanol, a bioactive compound from rice bran oil, is known for its strong antioxidant properties. It helps lower LDL, raise HDL, and offers anti-inflammatory benefits for conditions like hyperlipidemia, arthritis, and heart health. It is also used in supplements to support heart health, metabolism, muscle recovery, and reduce oxidative stress.

Rice Bran Oil in Functional Foods

Rice bran oil (RBO) is valued for its heart-healthy properties, rich in tocotrienols, tocopherols, and phytosterols. Tocotrienols reduce oxidative stress and blood pressure, while phytosterols block cholesterol absorption. RBO also offers anti-aging benefits by supporting skin health. Additionally, it is used in functional food products like fortified spreads, dressings, and snacks for health-conscious consumers.

Fermented Rice Bran Extracts

Fermentation of rice bran by beneficial microorganisms like *Lactobacillus* and *Saccharomyces* enhances its bioavailability and functional properties. Fermented rice bran extract (FRBE) supports gut health with prebiotics and probiotics that improve digestion and immunity. It also offers immunomodulatory effects, rich in bioactive peptides and polyphenols, boosting immunity and possessing anti-carcinogenic properties. FRBE is used in probiotic formulations such as beverages, capsules, and powders for digestive health.

Environmental and Biotechnological Applications

Wastewater Remediation

Rice by-products, especially rice husk, are effective in wastewater remediation due to their high silica and carbon content, offering a sustainable solution for treating contaminated water.

Rice Husk Adsorbents

Rice husk is a promising adsorbent for removing pollutants from industrial wastewater. It effectively binds heavy metals like cadmium, lead, chromium, and arsenic through ion exchange and surface adsorption. Additionally, rice husk adsorbs synthetic dyes, reducing environmental harm. As a biodegradable material, rice husk offers an eco-friendly solution, avoiding secondary pollutants commonly associated with chemical coagulants.

Activated Carbon from Rice Husk

Converting rice husk into activated carbon boosts its adsorption capacity, offering a sustainable, cost-effective solution for water purification, particularly in developing countries. The process involves pyrolysis and chemical activation with substances like potassium hydroxide, which increases the surface area of the husk. This activated carbon is effective in removing impurities such as organic matter, chlorine, and microbes from water. It is 30-50% cheaper than traditional carbon, making it an economical choice for small industries and rural communities.

Advantages of Rice Husk for Wastewater Treatment

The abundant availability and low cost of rice husk make it a sustainable and affordable solution for wastewater remediation. By repurposing agricultural waste, it supports the circular economy, reduces reliance on non-renewable resources, and promotes environmental sustainability. This approach helps address water pollution while fostering a more resilient ecosystem.

Energy Conservation

Paddy by-products like broken rice, rice husk, and straw contribute to energy conservation through bioethanol production and biogas generation. These applications reduce fossil fuel dependence and support the circular economy by converting agricultural waste into renewable energy.

Bioethanol Production

Bioethanol is produced from broken rice (60–70% starch) and rice straw (high cellulose), with broken rice yielding 250–300 liters per ton and rice straw producing 180–200 liters. Bioethanol reduces greenhouse gas emissions by 70% and helps manage agricultural waste. Biogas, generated from rice husk and pre-treated rice straw through anaerobic digestion, provides renewable energy for cooking, heating, and electricity. In India, biogas from rice husk meets 5–7% of rural energy needs, with one ton of rice straw producing 250–300 cubic meters of biogas, equivalent to 150 liters of diesel, reducing reliance on firewood, promoting waste reduction, and supporting environmental conservation.

Economic and Social Benefits

Using rice husk and straw for energy generation reduces costs, manages waste, and creates jobs. Replacing conventional fuels with biogas and bioethanol lowers energy expenses while preventing harmful rice straw burning. Setting up biogas and bioethanol plants also boosts rural employment and economic growth, promoting sustainable energy, environmental protection, and socio-economic development.

Conclusion

Paddy by-products, once seen as waste, now offer significant potential for sustainable development across the food, feed, industrial, and environmental sectors. By utilizing rice husk, bran, straw, and broken rice, we can minimize waste, reduce pollution, and promote economic growth. Advancements in processing technologies and expanding industrial applications could generate billions annually, making rice farming more profitable and eco-friendlier. Integrating paddy by-products into existing industries supports a circular economy, reduces dependence on non-renewable resources, and aids in climate change mitigation. Collaboration among policymakers, researchers, industries, and farmers is key to unlocking their full potential. Maximizing the value of these by-products not only boosts livelihoods but also promotes sustainable agricultural practices and global environmental conservation.

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