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Review on Physical, Mechanical and Nutritional Properties of Brown Rice

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Abstract

Rice (*Oryza sativa* L.) is a major staple crop worldwide, and its production, postharvest processing, and nutritional quality are critical for global food security. This review examined the current knowledge on rice cultivation, milling practices, and nutritional composition, highlighting the advantages of modern technologies over traditional methods. Traditional rice cultivation and milling were labour-intensive, time-consuming, and less efficient. In contrast, direct-seeded rice cultivation and improved milling systems significantly enhanced productivity, capacity utilization, and head rice recovery. Moisture content played a crucial role in determining the physical and mechanical properties of paddy, affecting grain rupture force, energy requirement, bulk density, and thousand-grain weight, which in turn influenced milling efficiency and grain quality. Comparative studies on rice cultivars from Ghana, India, and Egypt revealed no significant differences in key milling traits, suggesting that postharvest technologies could be widely applied across diverse varieties. Nutritionally, brown and red rice were superior to white rice, containing higher levels of protein, fat, dietary fibre, minerals, and antioxidant compounds. Red rice, in particular, exhibited greater starch yield and improved functional properties. The review emphasized that optimizing grain moisture during processing, adopting modern milling technologies, and promoting nutrient-rich rice varieties were essential strategies to enhance postharvest efficiency, minimize grain losses, and support sustainable rice production. These findings provide valuable insights for researchers, policymakers, and farmers aiming to improve rice quality, increase processing efficiency, and achieve sustainable cultivation practices that meet nutritional and economic goals.

Keywords: *Oryza sativa*, milling, moisture content, nutritional quality etc.

1. Introduction

Rice (*Oryza sativa* L.) is one of the most important staple food crops for more than half of the world's population, and as it is extensively cultivated across the world, it is known as "Global Grain"(Sadhu et al., 2024). It is obtained by processing paddy and provides essential nutrients, playing a crucial role in food security. Currently, global rice production is estimated at around 508.7 mt, cultivated over approximately 156 mha. Asia dominates the global rice industry, contributing nearly 90% of production, with more than 75% of the harvested rice consumed within the continent (Anonymous, 2024). Asia's contribution to rice production and consumption is more than 90% in the world (Bandumula, 2018; Sharma and Khanna, 2020; Venmuhil et al., 2020). Indeed, Asians get 60% of their calories from rice (Khush, 1997; Singh et al., 2023). China holds 1st rank in rice production, contributing over 28%, followed by India, accounting for about 22%, and Indonesia with 10%, of the world's total rice production (Anonymous, 2017). In Maharashtra, rice ranks as the second most important crop after other cereals. The state cultivates rice over an area of 1.69 mha, producing roughly 4.0 mmt, with an average productivity of 2.37 t ha^{-1} (Anonymous, 2025).

The Konkan region of Maharashtra is traditionally a rice-growing area, where transplanted rice is the dominant method of cultivation. Transplanting generally produces higher yields compared to direct seeding; however, it is a labour-intensive process involving nursery raising, puddling, and transplanting. With rapid urbanization and increasing labour scarcity in the region, these conventional practices face significant challenges. The direct-seeded rice (DSR) technique is gaining popularity because of its low input demand compared to PTR. It is done by sowing pre-germinated seeds in puddled soil (wet-DSR), standing water (water seeding), or dry seeding on a prepared seedbed (dryDSR). DSR requires less water and labor (12–35%), reduces methane emissions (10–90%), improves soil physical properties, involves less drudgery and production cost (US$9–125 ha^{-1}), and gives comparable yields (Choudhary et al., 2023). The Konkan region is one of the major rice-producing areas of Maharashtra, recognized as a predominant rice-growing belt. The region, consisting of the districts of Thane, Palghar, Raigad, Ratnagiri, and Sindhudurg, exhibits an average rice productivity of approximately 33.5 q ha^{-1} (Gawai et al., 2024). During the Kharif season of 2019, rice was cultivated on 392,392 ha, accounting for nearly 89% of the total sown area in the region. Rice yields in the Konkan vary depending on the variety. High-yielding varieties typically produce between 2,500 and 3,500 kg ha^{-1}**,** while hybrid varieties can yield 3,500 to 4,500 kg ha^{-1}. Farmers in the region generally use a seed rate of 50–60 kg ha^{-1}, reflecting traditional cultivation practices and the potential for improved productivity through modern agronomic interventions (Anonymous 3, 2020). Its texture determines the qualities of rice during cooking, flavour, and nutritional value. The primary parameter is the physical appearance of rice kernel quality, which directly influences consumers' willingness to purchase (Custodio et al., 2019). According to market requirements and consumer preferences, rice grains are distinguished and grouped into four types of classes (extra-long, long, medium, and short) based on their size, shape, and nutritional properties. (Chrungoo and Devi, 2015). The objective of the present study was to determine the physical, mechanical, and nutritional quality parameters of brown rice (Muhammed et al., 2025)

2. Milling History, Physical, Mechanical and Nutritional Properties of Paddy

2.1. Milling history

Rice milling has evolved from traditional, labour-intensive methods such as hand pounding and water-powered mills (Paani Ghatta), which were slow and prone to high grain damage, to mechanized systems that improved efficiency and recovery (Khatri et al., 2020).

A thorough review of literature was carried out for the study titled *"Review on Physical, Mechanical and Nutritional Properties of Brown Rice."* This review integrates important research findings related to milling techniques along with the physical, mechanical, and nutritional characteristics of paddy and brown rice, thereby establishing a strong scientific basis for understanding its processing behaviour and nutritional value. Milling, being a key post-harvest operation, has a direct impact on the efficiency and quality of rice production. Tangpinijkul (2010) investigated both conventional and modern milling systems and reported that traditional steel hullers have a relatively low capacity of around 35 kg hr^{-1}, whereas modern small-scale mills can process between 150 and 550 kg hr^{-1}, demonstrating a clear performance improvement. Similarly, Mahajanashetti et al. (2011) examined efficiency parameters of different rice mills and found that modern mills achieve higher capacity utilization (69%) compared to conventional mills (44%), along with better recovery rates of head rice (73%) and bran (8%) than traditional mills. In addition, Rehman et al. (2017) highlighted that automated rice mills ensure cleaner processing with fewer impurities and significantly higher output, exceeding 2 t hr^{-1}, while traditional mills typically produce only 0.6 to 1 t hr^{-1}. Furthermore, Khatri et al. (2020) emphasized that traditional milling methods such as water mills (*Paani Ghatta*) and manual pounding are time-consuming, labour-intensive, and inefficient, thereby underscoring the need for cost-effective, multifunctional rice milling machines to enhance productivity and reduce labour requirements in post-harvest processing.

2.2. Physical characteristics of paddy

A thorough review of literature was carried out for the study titled "Review on Physical, Mechanical and Nutritional Properties of Brown Rice." This review integrates key research findings on moisture content, physical properties, and their effects on rice grain behaviour, milling performance, and post-harvest processing efficiency. Firouzi et al. (2010) investigated the effect of paddy moisture content at three levels (8–9%, 10–11%, and 12–13% w.b.) on the husking index and the percentage of broken rice. The study revealed that higher moisture content increased the proportion of broken kernels from 13% to 14.61% while reducing the husking index, indicating decreased husk removal efficiency. Bagheri et al. (2011) examined the mechanical strength of 12 brown rice varieties at moisture levels of 8%, 10%, 12%, and 14%, and reported that rupture force decreased with increasing moisture content. At low moisture, grains failed suddenly with minimal deformation, whereas at higher moisture, failure was gradual with greater deformation, reflecting more ductile behaviour.

Rasaaq et al. (2011) evaluated the static coefficient of friction of five improved paddy varieties and found that it increased with rising moisture content, affecting grain flowability and handling. Sadeghi et al. (2012) studied head rice yield and degree of milling in three rice varieties, reporting that an increase in moisture from 8% to 14% decreased head rice yield from 65.5% to 60.7% while slightly increasing the degree of milling. Kumar et al. (2018) observed that 14% moisture content minimized grain breakage and increased head rice yield in cold-tolerant varieties. Sooksawat et al. (2020) highlighted that physical traits such as grain size, shape, and thickness influence cooking behaviour, with thinner grains absorbing more water and expanding more than thicker grains. Almasoud et al. (2024), Azman et al. (2025), and Mydeen et al. (2025) further reported that physical and engineering properties, including grain dimensions, sphericity, aspect ratio, density, porosity, and surface area, play a critical role in milling recovery, post-harvest handling, and machinery design. Overall, these studies demonstrate that both moisture content and grain physical properties are fundamental factors in determining rice quality, milling efficiency, and post-harvest processing performance.

2.3. Mechanical characteristics of paddy

The mechanical characteristics of paddy are important because they determine how rice grains respond to forces during harvesting, handling, storage, and milling, directly affecting grain breakage, milling efficiency, and postharvest losses. Properties such as rupture force, energy absorbed at fracture, hardness, elasticity, and crushing strength are influenced by factors including moisture content, grain variety, and loading conditions. For example, higher moisture content reduces the force required to break grains but increases the energy they absorb, while genetic differences among varieties affect bulk density, sphericity, and fracture resistance. Understanding these characteristics is essential for designing efficient agricultural machinery, storage systems, and milling equipment, as well as for optimizing postharvest processes, minimizing grain damage, and ensuring better rice quality.

Zareiforoush et al. (2012) examined the mechanical behavior of rice kernels during de-husking and milling at the Department of Agricultural Machinery, University of Urmia, Iran. The study focused on the fracture resistance of paddy grains by measuring rupture force and energy. Paddy grains were tested in both horizontal and vertical orientations at moisture contents of 8%, 11%, and 14% (w.b) with loading rates of 5 and 10 mm/min. Results indicated that as moisture content increased, the force required to cause grain rupture decreased from 167.70 to 88.33 N and 43.55 to 21.68 N, while the energy absorbed at rupture increased from 13.08 to 34.39 mg and 10.38 to 26.98 mg, respectively. Similarly, Singh and Prasad (2013) assessed the effects of milling and shelling on the physical characteristics of paddy at Sant Longowal Institute of Engineering and Technology, Punjab. Brown rice yields for varieties Pusa 1121, Muchhal, Sughanda, Shabnam, and Usha ranged between 77.63% and 78.98%, with overall milled rice recovery from 72.30% to 73.16%. Husk and bran accounted for 21.02%–22.37% and 5.25%–5.97%, respectively. The study concluded that longer paddy grains were more prone to damage during milling and shelling. Pandiselvam and Venkatachalam (2014) reported that for paddy variety ADT-43, increasing moisture content from 11.86% to 23.61% (d.b) resulted in higher thousand-grain weight, surface area, volume, equivalent diameter, sphericity, and bulk density, whereas porosity and true density decreased.

In terms of nutritional value, Choudhary et al. (2018) found that rice contains approximately 80% carbohydrates, 7–8% protein, 3% fat, and 3% fiber, and possesses potential health benefits in managing conditions such as diabetes, hyperlipidaemia, cancer, and inflammation. The study highlighted rice as a rich source of antioxidants, with potential applications in functional foods, pharmaceuticals, food preservatives, and cosmetics. Opoku et al. (2024) evaluated the mechanical properties of four Ghanaian rice varieties, AGRA, CRI-Amankwatia, CRI-Enapa, and CRI-Dartey at moisture contents of 11.5%, 13.0%, and 16.5% (w.b). CRI-Dartey at 16.5% exhibited the highest sphericity and aspect ratio, AGRA at 13% showed the highest grain mass and true density, CRI-Amankwatia at 16.5% had the highest 1000-grain mass, angle of repose, and bulk density, and CRI-Enapa at 11.5% displayed the highest porosity. Liu et al. (2025) investigated mechanical damage in three brown rice varieties: Hunan Early Indica 45, Hunan Glutinous 28, and Southern Japonica 518 under single and continuous compression. Maximum destructive forces ranged from 115.64 to 134.77 N, crushing deformations from 0.43 to 0.51 mm, and damage ratios from 12.24% to 14.35%. These studies collectively provide valuable insights into how moisture, grain variety, and processing conditions affect the mechanical, physical, and nutritional characteristics of rice, offering guidance for improving postharvest handling, milling efficiency, and overall rice quality.

2.4. Nutritional characteristics of paddy

Investigating the nutritional characteristics of paddy is essential because it reveals the levels of proteins, carbohydrates, fats, fiber, vitamins, minerals, and bioactive compounds in the grain, which are critical for human health and balanced diets. This information allows for the identification of rice varieties with superior nutritional value and supports the development of functional foods, fortified products, and health-oriented dietary strategies. Moreover, understanding the nutrient composition of paddy is important for optimizing processing, milling, and storage practices to preserve essential nutrients, minimize postharvest losses, and provide guidance for public health policies and food security planning.

Rohman et al. (2014) first examined the nutritional composition of white and brown rice at Gadjah Mada University, Indonesia, emphasizing the benefits of rice bran and defatted rice bran. They found that 100 g of white rice contains 10.46 g water, 6.81 g protein, 0.55 g fat, and 81.86 g carbohydrates, whereas 100 g of brown rice flour contains 11.97 g water, 7.20 g protein, 2.78 g fat, 76.48 g carbohydrates, and 4.6 g fiber. This comparison highlights that brown rice provides higher amounts of protein, fat, and dietary fiber while having a lower carbohydrate content, suggesting its suitability for nutrient-rich diets and functional foods. Following this, Raghuvanshi et al. (2017) investigated the nutritional quality of locally grown red and white rice in India, reporting that red rice contains higher levels of essential minerals, including iron, magnesium, calcium, and zinc, as well as increased crude protein, fiber, and fat compared to white rice, reinforcing the value of pigmented rice varieties as nutrient-dense foods. Building on these findings, Upadhyay and Kumar (2018) highlighted that brown rice not only provides essential macronutrients such as protein, carbohydrates, and fiber but also contains micronutrients like iron, zinc, thiamine, niacin, and vitamin E, along with bioactive compounds including γ-oryzanols, tocotrienols, and polyphenols. Its low glycemic index supports blood sugar management, particularly for individuals with type II diabetes. Saleh et al. (2019) further confirmed these results, showing that brown rice consistently has higher protein, fat, and fiber content compared to white rice, while white rice has a higher proportion of carbohydrates and lower ash content, demonstrating the nutritional advantage of retaining the bran layer.

Expanding on the nutritional and functional potential of pigmented rice, Joshi and Sankhala (2021) analyzed an organically cultivated red rice variety, which contained 9.6 g protein, 1.7 g fat, 2.3 g crude fiber, 73.3 g carbohydrates, 347 kcal energy, and significant amounts of calcium, iron, and zinc per 100 g. The study also reported 65.4% protein digestibility, 15% iron absorption, low levels of anti-nutritional factors (tannins 0.29%, phytates 0.96%), and strong antioxidant activity (75%). Complementing this, Choudhary et al. (2025) studied starch extracted from red and white rice and found that red rice starch had a higher yield (65% vs. 58% in white rice), higher water and oil absorption, and distinct molecular and structural properties, including 82.5% starch and 25.71% amylose. These findings collectively suggest a sequential trend: as rice retains more of its bran and pigmented layers from white to brown to red the nutritional and functional properties improve, making these varieties increasingly suitable for health-focused diets, functional food development, and sustainable rice processing.

3. Conclusion

Modern rice milling systems are more efficient than traditional methods, with higher capacities, utilization, and head rice recovery. Moisture content significantly affects physical and mechanical properties, while Ghanaian rice varieties show no major differences in key traits, allowing technologies to be applied broadly. Nutritionally, brown and red rice outperform white rice in protein, fat, fiber, minerals, and antioxidant activity. Optimizing moisture, using modern mills, and promoting nutrient-rich varieties are key to reducing postharvest losses and improving sustainable rice production.

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