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Review Article

Key Factors Affecting the Quality of Milling Recovery in Rice Processing

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Abstract

Rice is the kernel of the grass 'Oryza sativa' L. Over 50 percent of the global population relies on this cereal grain as a staple food. This review aims to investigate and understand various rice processing techniques and machines, the causes of rice milling loss, and the remedies proposed by scholars. Rice processing refers to the extraction of edible grains from rice paddy. De-husking, de-hulling, and shelling are terms used to describe the removal of the husk, the outermost layer of the rice grain. This is typically accomplished using a de-husking machine, such as the Engelberg model (which uses a metal roller) or the SB type (which uses a rubber roller and a compacted rice mill). The next step is milling rice, which involves the removal of the bran, the innermost layer of the grain. This process is also known as polishing. In modern rice processing plants, polishing refers to shaping or smoothing the milled rice's surface. Rice grain-producing countries often experience high post-harvest processing losses due to poor physical qualities of rice varieties, inefficiencies in processing technologies, and equipment malfunctions. The percentage of postharvest loss is particularly high in developing countries where traditional and outdated processing methods are commonly used. As a result, rice processing requires careful attention and should be carried out by trained professionals. Therefore, this paper discusses the methods of rice processing and the factors that affect the quality of processed rice.

Keywords

De-husking, Factors, Milling Recovery, Polishing, Rice Processing

1. Introduction

Rice is a widely cultivated crop grain or kernel with two distinct layers [1, 2]: the innermost layer (bran) and the outermost layer (husk) [3]. For a significant portion of the world's population, rice is a primary source of nutrition [4-7]. Rice is genetically diverse, with thousands of varieties grown across the globe [8, 9]. Approximately two-thirds of the world's population depends on rice, one of the most important nutrients for humans [10]. It is deeply embedded in the cultural history of many nations [11]. Global demand for rice continues to rise each year, particularly in Africa [12, 6]. However, production falls significantly short of consumption [9]. While demand is growing rapidly, rice farming is increasing at a slower pace [13]. Asian countries dominate global rice production [14]), with India having the largest rice farming area. In Sub-Saharan Africa (SSA), rice is the fastest-growing food product [15, 6] and is critical to food security [4]. Over 750 million people in SSA depend on rice, and its demand is increasing faster than that of any other

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staple food as consumer preferences shift [16, 8, 17].

Paddy becomes edible once the husk and bran layers are completely removed through various milling processes [18]. Brown rice, the primary consumable product in the rice milling chain, consists of bran and is produced when the outer husk layer is eliminated during the de-husking process [19, 20]. Several factors influence rice milling performance, including the loss of moisture content beyond acceptable levels [3]. Milling efficiency is typically measured regarding head rice yield or kernel quality [21, 16]. Proper machinery selection and careful operation are crucial for achieving optimal results [22]. According to [23], milling significantly impacts the final form of processed rice. This study aimed to analyze various rice milling procedures and identify areas for future research that could improve head rice recovery during milling.

2. Principles of Rice Processing

Rice processing refers to the operations that occur after threshing and continue through to the production of refined white rice [7]. Rice milling removes the husk and bran from paddy kernels to produce polished rice [5, 7]. This milling process transforms the rice grain into a form suitable for human consumption [24]. Therefore, great care must be taken to prevent kernel damage and maximize recovery [14]. Milling is a crucial stage in the rice production process, where the goal is to remove the husk and bran layers, resulting in an edible, and white rice kernel that is properly processed and free of contaminants [25, 26]. Depending on consumer preference, the rice should have a minimal number of cracked kernels [27, 14]. The conversion of paddy into white rice involves several steps, each of which must be tailored to the specific rice cultivars [28]. Milling plays a vital role in controlling the overall quality and minimizing nutritional loss of brown rice, while also improving consumer acceptance [8, 29].

The three primary indicators used to assess milling quality are brown rice return (the quantity of brown rice produced from rough rice), milled rice recovery (the percentage of milled grain obtained from rough rice), and head rice recovery [30, 31]. Milling can be done in a single pass, two passes, or through today's multistage processes [26]. Rice milling relies on applying shear and compression forces [32]. Many factors affect the quality of rice milling, including genetic variations between cultivars, environmental conditions during cultivation, the milling machinery used, and the optimization of milling processes [33].

2.1. Structures of the Paddy

Rice grain consists of three layers: the husk, bran, and endosperm [34]. The husk layer (comprised of the lemma and palea) accounts for approximately 20% of the weight of paddy and serves to protect the grain kernel from insects and fungal attacks [3, 35] (Table 1). The milling degree refers to the extent to which the bran layer is removed [3]. Due to its oily nature, rice is vulnerable to insect infestations once milled, so removing the entire bran layer helps extend its shelf life [11, 14]. Rice bran, a byproduct of the brown rice milling process, is produced during the conversion of paddy to white rice [29]. This 'bran' is further processed for oil extraction [18].

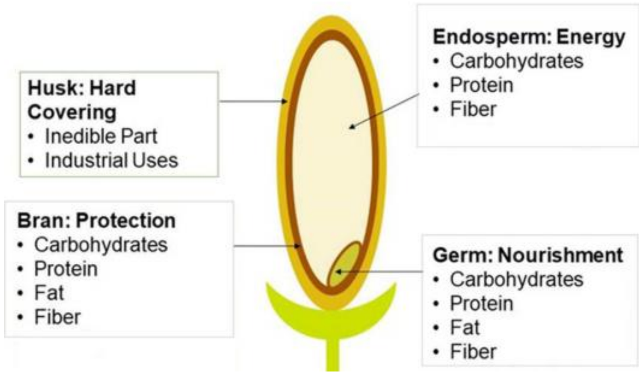

Figure 1. *Grain structures of the rice kernel [36, 26].*

According to [36], rice is composed of 20% husk, 80% brown rice, and the pericarp and testa range 5-6%.

Table 1. *Physical composition of paddy.*

Physical properties	Percentage
Husk	20
Brown rice, BR	80
Pericarp and testa	5-6
Aleurone	1
Embryo	3
White rice	70-72

Rice composition varies with variety and agroecology [37, 38].

2.2. Development of Rice Milling Machines

In the past, pestles, mortars, and basic hand tools were used for dehusking [39]. Hand pounding of paddy removes the husk and bran layers from the grain by applying upward and downward forces [40]. Additionally, hammering often results in cracking the grain [41]. Traditional rice mills were powered by human energy, which is recognized as a renewable and environmentally friendly energy source [42]. Today, rice is milled by passing it between two rollers with abrasive surfaces that rotate at different speeds [43].

Figure 2. *Traditional hulling with mortar and pestle.*

2.3. Types of Rice Processing Machines

2.3.1. Vertical and Horizontal Machines

The arrangement of the shafts, rollers, and other moving components determines whether the rice processing machines are designed to be vertical or horizontal [44]. In a vertically oriented machine, the paddy moves downhill in a vertical direction. In contrast, in a horizontally oriented machine, the paddy is first loaded into a vertical bucket and then travels horizontally towards the de-husking and polishing units [45].

2.3.2. One-pass, Double-pass, and Multi-staged Machines

Rice processing machines can be classified as single-pass, double-pass, or multi-stage, depending on the number of steps involved in producing white rice [46]. Single-pass rice processing machines produce polished white rice in a single unit [39]. These mills are still commonly used for custom milling of domestic rice and are especially popular in many less advanced rice-growing countries [47].

These mills typically employ a metal friction method that uses high pressure to polish the grain and separate the hulls [48]. However, this process results in poor white rice recovery (50-55%), a high proportion of cracked kernels, and head rice yields of less than 30% when fully milled [49]. Double-pass mills generate brown rice in two stages, followed by the production of white rice [50].

According to [3], multi-stage machines integrate several unit operations that can be independently controlled. These include graders (which sort grain based on size and other quality parameters), color sorters (which remove defective colored grains), huskers (which eliminate stones, sand, and soil materials), millers (which remove the bran), polishers (which blow away lighter materials like straw fragments), and packaging units [51].

Rice processing machines are classified into two types based on the roller material: steel rollers (such as the Engelberg brand) and rubber rollers (such as the SB series) [45]. The Engelberg milling machine, invented in the United States in 1890, was originally designed to remove the pericarp from coffee beans. These machines can process 500-800 kg of paddy rice per hour [52, 53]. However, they are increasingly being replaced by rubber roll-type rice milling machines, which offer significantly improved performance and lower breakage rates [15]. Rubber rolls, developed in the late 1920s as a de-husking medium for paddy rice, are now the most widely used and efficient type of rice milling machine [14].

a) b) c) d)

Figure 3. *(a, b) Engelberg type rice mill, (c, d) SB type rubber roll rice mill.*

2.4. Major Rice Processing Steps

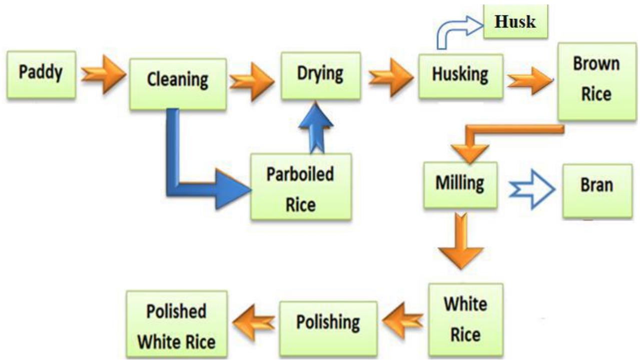

Figure 4. *Rice processing paths.*

2.4.1. Cleaning

When paddy enters the mill, it often contains foreign materials such as straw, weed seeds, dirt, and other inert substances [54]. If these impurities are not removed before hulling, they can reduce the efficiency of the hullers and lower milling yields [55]. Typically, the paddy pre-cleaner is designed to have a capacity 1.5 times greater than that of the mill. Cleaning refers to the process of removing foreign materials from paddy, such as sand, stones, straw, and other seeds [47]. The cleaning method relies on the physical properties of the mixture, such as weight, size, and density, with aspirators removing contaminants that are lighter than the paddy [56].

Before processing, paddy rice from storage must undergo dry cleaning to eliminate straws, stones, and other foreign materials [54]. Threshed rice from the field is often contaminated with various impurities. In many developing countries, mechanized threshing is not widely used, leading to higher levels of contamination. Soil is the primary contaminant, affecting the color, taste, and odor of the processed rice [57].

a) b) c)

Figure 5. *Cleaning technologies. a) traditional b) manually operated c) paddy cleaning machine.*

2.4.2. Parboiling

Parboiling is a hydrothermal process applied to paddy, involving soaking, steeping, and steaming to produce parboiled white or brown rice [58, 14, 27]. Soaking involves immersing the paddy in either normal or hot water for a specified duration [14]. This process includes molecular intake, capillary absorption, and hydration [59]. After soaking, the paddy is steamed or partially cooked in boiling water or moist steam [60]. Steaming inactivates enzymes gelatinizes the endosperm, and seals the break in the caryopsis [61, 62].

2.4.3. Drying

Rice drying and tempering have been practiced for a long time, but they are often carried out improperly due to factors such as energy costs, lack of expertise, and other variables [63, 64]. This leads to significant losses in both quantity and quality [65]. To improve the process, various aspects of drying have been studied [66]. The moisture content is reduced to the appropriate level during the drying process [38, 67]. Paddy drying consumes a considerable amount of energy and affects the quality of the final product. Milling quality is primarily influenced by the extent of paddy drying [68]. Over-dried paddy results in poor milling recovery [64]. Properly dried paddy, with an optimal moisture content of 12-15%, ensures the best head rice production [27]. Over-drying also has an economic impact, as it leads to a higher proportion of broken rice due to the reduced moisture content [57].

2.4.4. The De-Husking Process and Types of De-husking Machines

The terms "de-husking," "de-hulling," or "shelling" refer to the process of removing the husk from the paddy. Mechanical methods are used to detach the hull or shell from the rice kernels [69]. Several devices employing different techniques have been developed to improve the efficiency of the dehusking process [42]. Friction is used to separate the husk layer from the paddy [48]. The husk is then removed using suction (aspiration) and directed to a storage dump outside the milling machine [44]. Hulling efficiency refers to the proportion of paddy that is de-hulled during the brown rice production process. A high-quality husker will remove 90% of the husk in a single pass. Once the outer covering is removed, the brown rice is sent to a paddy separator [54]. Any kernels that were not de-husked during the initial process are extracted and sent back to the de-husker [70].

The husk constitutes about 20% of the total mass of paddy, and an efficient husker should remove 90% of the outer layer in a single pass. Brown rice is produced by hulling rough paddy rice, which involves passing the paddy grains over two abrasive surfaces moving at different speeds. Suction is then used to remove the husk, which is subsequently transferred to a storage dump outside the mill [71, 54].

A) Centrifugal Sheller/Husker

Centrifugal shellers utilize a spinning impeller to separate the husks from the paddy grains, which are driven toward the outer casing by rotational force. The shelling process occurs in the outer casing due to strong impacts [54]. With a simple design, the centrifugal sheller consists of a single moving part, the impeller, and offers high capacity. The interior surface of the casing, where rice grains collide, is lined with rubber. The rotor's center receives the paddy feed. This equipment can easily be converted into a small multistage mill by combining multiple components [29].

B) Disc Sheller

Disc shellers are primarily composed of two abrasive discs that either rotate or are fixed in opposing directions [72]. Dehusking occurs between the two discs. The most affordable machine in this category is the underrunning disc sheller [73]. It consists of two discs with inner faces lined with an emery roller; one disc rotates while the other remains stationary. The paddy is de-husked as it passes through the gap between the discs. This type of sheller offers a significant increase (2-4%) in rice yield compared to traditional hullers in nearly all milling conditions [74, 44].

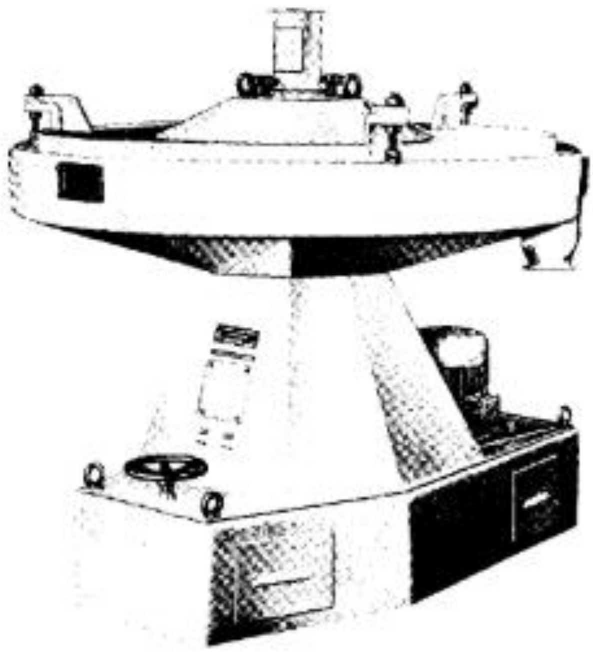

Figure 6. *Disc type sheller.*

2.4.5. Rubber Roll Sheller

Paddy grains are passed between two rubber rollers, which rotate in opposing directions at different speeds to maximize the shearing force on the grains, effectively loosening and removing the husk [45]. Throughout the dehulling process, the grains are handled carefully due to the compressible and flexible nature of the rubber rollers [68]. This gentle handling is why rubber roll shellers typically have a higher head rice recovery rate compared to other types of shellers [75]. The rubber roller mill produces higher-quality brown rice, which is often more desirable in the market and commands higher prices [38, 76].

2.4.6. Paddy Separation

The paddy separator separates unhusked paddy rice from brown rice [54]. The amount of paddy present after dehusking depends on the efficiency of the husker and should not exceed 10% [43]. Paddy separators use differences in specific gravity, buoyancy, and size to distinguish between paddy and brown rice [77].

2.4.7. Milling Process and Types of Milling Machines

White rice is produced by removing the bran layer and germ from paddy grains [3]. The bran layer is removed using either abrasive or friction polishers, with the amount of bran removed typically ranging between 8% and 10% of the total paddy weight [72]. Rice is often processed through two to four whitening machines connected in series to minimize the quantity of damaged grains [27]. Milling or polishing involves the removal of the bran layer [51]. There are two main types of polishers used commercially in rice milling: abrasive and friction polishers [78]. Milling quality, (MQ) refers to the rice kernels' ability to withstand dehusking and polishing with minimal breakage, resulting in high recovery rates. It directly impacts the yield and the proportion of cracked kernels in the milled rice [38, 6]. The percentage of broken rice increases due to poor surface hardness, leading to lower milled rice quality and recovery [79]. MQ not only influences the overall quality of the rice but also affects its appearance [29]. It is widely acknowledged that higher levels of milling can lead to increased food waste, which has had negative impacts on the prosperity of some countries [80].

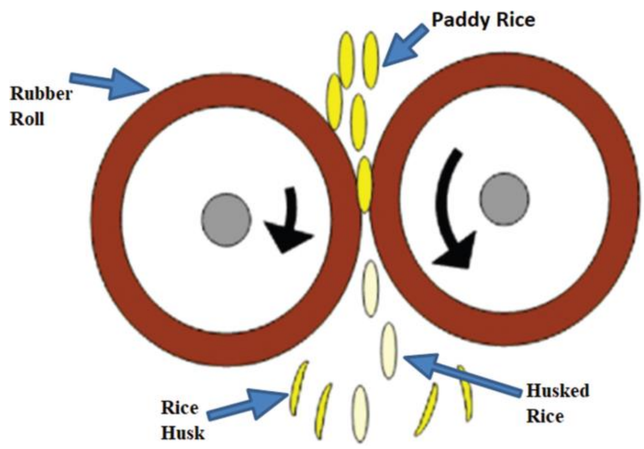

Figure 7. *Working principle of a rubber roll husker [51, 27].*

After polishing, an oscillating screen sifter separates white rice into head rice, big and tiny broken rice, and "brewers" [38]. Head rice is defined as kernels that are 75-80% or more of the complete [71]. The length or indent classifier is used to provide more precision for grading and separation [28].

A) Vertical Milling Machine

A vertical shaft supports a cone-shaped cast iron cylinder with an abrasive surface, surrounded by a sieve with adjustable clearances [45]. An adjustable rubber brake separates the screen at regular intervals, helping to minimize rice breakage [81]. A hopper feeds the husked rice into the upper center of the cone [45, 82]. As the cone spins, centrifugal force pushes the brown rice toward the cone and the wire mesh/sieve [83]. To produce brown rice with minimal loss of bran layers, the clearance and residence time of the rollers must be carefully adjusted according to the specific size and variety of the rice [44].

B) Horizontal milling machines

A permanent horizontal sieve and a spinning emery roller are both concentrically positioned in a milling chamber [84]. The roller and sieve ensure a uniform clearance [44]. The husked rice is passed between a roller and filter; polishing is achieved [85].

C) Air-Jet-Based Polisher

In this type of machine, air-jet streams are used to remove the bran coating from the husked rice [51]. The machine is relatively efficient for short-grain varieties but performs moderately for medium and long-grain types, often resulting in a higher percentage of broken rice [86]. It consists of a horizontal, partially hollow perforated shaft, on which a cast steel cylinder with friction ridges is mounted. The clearance between the hexagonal screen and the cast steel cylinder is adjustable [44].

2.4.8. Grading and Packaging

After polishing, the milled rice is expected to consist of head rice (unbroken rice) and broken rice in various sizes [82]. The broken rice is separated from the head rice using stage sieve equipment. Polished rice can then be sorted and graded as necessary [71]. Spectral analysis can be employed to differentiate pure rice from red or abnormal-colored rice seeds, sorting them based on their structural features [87]. Large broken and whole grains are either packed for delivery to the client or further refined using length graders [80]. Once the rice has been analyzed and classified according to specific requirements, the next step is to package and bag it in appropriate sizes using non-contaminating materials. Grading should be based on the quality standards required, and packaging sizes, such as 1 ton, 5 tons, 10 tons, or others, can be specified for commercial purposes [10].

3. Factors Affecting the Milling Recovery

Many factors influence rice milling recovery, including genotypic variations between rice cultivars, environmental conditions during rice cultivation, milling equipment, and expertise in milling processes [86]. Cultural and agronomic practices, such as cultivar selection, planting date, nitrogen delivery regime and its availability for plant use, harvest timing, and environmental factors, have all been studied for their impact on milling outcomes [88].

Factors affecting rice quality include varietal differences, environmental conditions during growth, harvesting, milling, drying, and storage, as well as the performance and adjustments made to milling technology [43]. These elements can impact the physical and mechanical properties of rice kernels, either directly or indirectly [89]. Agronomic factors such as water management, cultivar choice, harvest timing, paddy handling, and grain moisture content can all influence milling yield. The revenue of rice producers is largely determined by the yield, yield components, and quality of white rice produced through milling, as most rice farmers rely directly on the income generated from the quantity and quality of their rice [87].

3.1. Crop Factor

Rice cultivars exhibit significant differences in milling output [90]. Rice varieties with weaker characteristics, such as low hardness and toughness, as well as those with hollow grain spaces, are more prone to breakage [28]. The final form of the processed rice is largely determined by the milling process. Grain size and shape (length-to-width ratio) are highly consistent varietal traits. Long, slender grains are more prone to breakage compared to short, bold grains, which results in lower milled rice recovery [20]. The percentage of breakage increases with the degree of milling due to low surface hardness, leading to reduced quality and recovery of milled rice [29]. Due to genetic variations, different rice cultivars respond differently to cracking during milling [93]. The genetic makeup of rice affects its ability to absorb nitrogen, moisture absorption and desorption rates, and its resilience to breakage. The timing of planting is also critical for ensuring grain quality, milling yield, and recovery [94].

3.2. Environmental and Agronomic Factors

Agronomic practices such as cultivar selection, seeding date, nitrogen application regime and its availability for plant uptake, harvest timing, and environmental factors can all influence rice cracking during milling [94]. Cultivar choice and planting date have been identified as key factors affecting milling yield in studies conducted across various agroecological zones with differing climatic conditions [91]. Rice milling yield and breakage resistance are closely related to the nitrogen (N) supplying capacity of the soil, as well as the timing of nitrogen application during critical growth stages, particularly during panicle initiation and grain filling when nitrogen requirements peak [33].

3.3. Postharvest Management

Harvesting, threshing, drying, transportation, and storage methods all play a crucial role in determining the quality of processed rice [73]. Properly managed rice grain typically yields higher milling recovery and head rice yield [62]. Conversely, over-drying and poor handling can cause internal micro and macro fractures, leading to increased rice breakage when the grain enters the milling machine [3].

3.4. Machine Factor

Metal roller rice milling equipment produces more broken grains compared to rubber roll rice milling machines [74]. As the machine's capacity improves, the percentage of broken rice decreases [82]. The Engelberg-type rice husking mill is less efficient than the SB series rubber roll mills in terms of capacity, technology, quality, and milling recovery [68]. However, many studies indicate that due to budgetary constraints in acquiring better-performing equipment, processors often rely on lower-quality machinery, leading to a higher percentage of broken rice [95]. In contrast, rice processing equipment with rubber rolls causes minimal damage, yielding better milling results and higher recovery rates [23].

3.5. Operator Skill and Machine Adjustment Factor

Milling quality is influenced by various machine adjustments, including ground level, feed rate, dynamo /shaft revolutions per minute, power transmitting belt tension, knob adjustments, roller clearance, and product outlet opening settings [45]. Regular cleaning of the milling machine after use helps maintain its efficiency [54]. Rubber roll machines are ideally operated at 800 to 1000 rpm to achieve higher-quality rice [54]. During cleaning, it is essential to check the belt tension and tightness, as well as any loose nuts and bolts [55]. Additionally, the quantity of frictional forces, how they are applied, and the intensity of operation in the blade whitener should be adjusted to maximize bran separation [79].

3.6. Rice Breakage Reduction

The moisture content at harvesting, threshing, and milling should be optimal for efficient processing [80, 28]. Rice should have a moisture content of 20-25% at harvest, 15-20% when threshed, and 14-15% during milling [67]. In addition to machine performance, the quality of the rice cultivar also affects milling yield [62]. Rice cultivars with high stress tolerance are therefore recommended [91]. Delayed harvesting can reduce milling recovery [92]. Harvesting at the optimal moisture level can enhance head rice yield, whereas harvesting with low moisture content reduces drying costs but leads to a decrease in head rice production [93].

4. Conclusion

Rice processing is the most critical stage in determining the quality of rice. Several factors influence the percentage of milling recovery, with machine efficiency being the primary limiting factor. The rubber roll clearance for each rice type should be adjusted based on thickness using a filling gauge. Increasing the speed at which the rollers rotate leads to a higher percentage of broken rice. SB series machines (with rubber rolls) produce the least amount of broken rice when operated at speeds lower than 1000 rpm. In contrast, Engelberg-type mills (with steel rollers) tend to have a high breakage percentage despite their low rpm. To maximize milling recovery, it is recommended that the paddy moisture level be maintained at around 14% during rice processing.

Abbreviations

BR	Brown Rice
MQ	Milling Quality
N	Nitrogen
SSA	Sub-Saharan Africa

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Conflicts of Interest

The author declares no conflicts of interest.

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