Effect of Pre-milling on Milled Rice Breakage – A Review

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Abstract

Rice breakage during milling has long been a problem in rice-producing countries. The price of broken milled rice is about 50% lower than unbroken head rice, indicating the need for an investigation into the causes of rice kernel breakage. Decreased resistance of rice grains to mechanical stresses experienced in milling machines is the key source of milled rice breakage. Fissured, chalky, long, moist, immature, and soft grains have lower mechanical resistance and break more easily during milling. Some paddy cultivars have an inherent tendency toward chalkiness, decreased hardness, and resistance to fissuring. Ineffective agronomical methods, adverse environmental conditions, inappropriate harvesting parameters, and improper drying operations strongly affect formation of fissures, intensify chalkiness, and decrease the mechanical strength of rice grains. Among all postharvest operations, the positive effect of parboiling on strengthening paddy grains has been demonstrated, but the economic aspects and energy consumption for parboiling, especially in low income countries, is a main topic for future research. The complexity and multiplicity of the pre-milling parameters affecting milled rice breakage, particularly environmental and agronomical parameters, also require future research

Keywords: rice, paddy, breakage, post-harvest, milling

Introduction

Rice (*Oryza sativa* L.) is the second cereal crop and a staple food for about 2/3 of the world population (Zhout et al. 2002). It is a major source of energy, is hypoallergenic and easily digested, and provides protein with high nutritional quality. Rice is harvested as paddy or rough rice grain in the field. A paddy grain is 20% husk, 8-12% bran and embryo, and 70-72% endosperm, depending on the degree of milling (Saikia and Deka, 2011). The endosperm is the edible portion of the grain and is known as white or milled rice.

Dried paddy grains are subjected to milling to extract the edible kernel. Milling is the last stage in post-harvest rice production. It consists of husking and whitening or pearling. Husking is the act of removing the husk from the rough rice grain. In this operation, tension, compression, and friction forces are applied to the paddy grain to extract the brown rice (Juma omar and Yamashita, 1987). When the husk has been detached from the paddy grain, the brown rice kernel coated by a bran layer remains (Figure 1). The bran is more difficult to extract because it is firmly bonded to the endosperm. The process of detaching the bran from the brown rice is called whitening or pearling. During this operation, mechanical and thermal stresses are applied to the rice kernels and can cause breakage of kernels (Afzalinia, 2004).

Breakage decreases the value of rice by 30 to 50% of the value of head milled rice (kernels having length greater than ¾ of whole milled rice). The unit value of the paddy is based primarily for its head rice yield (HRY), which is the index used to quantify the quality of milled rice (Matthews and Spadaro, 1976; Lu and Siebenmorgen, 1995). HRY is the mass percentage of rough rice that remains as unbroken kernels (at least 75% of the whole kernel in length) after milling (Thakur and Gupta, 2006). Over-milling of rice grains may result in loss of rice during milling and can be assessed by the percentage milled rice (PMR) and degree of milling (DOM).

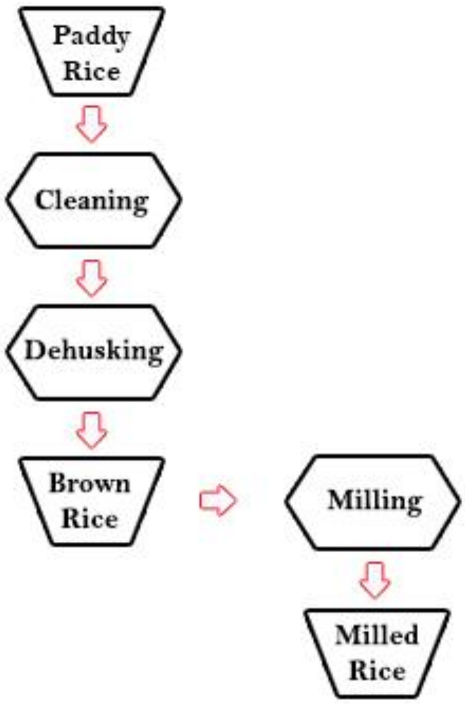

Figure 1 Main steps in rice milling.

PMR is the mass of milled rice as a percentage of initial rough rice that remains after milling. DOM is an index that represents the degree to which the bran layer is removed from the brown rice kernel during milling (Sarker and Farouk, 1989; Lu et al., 1994; Siebenmorgen and Sun, 1994). Other qualitative parameters that affect the value of milled rice are kernel size and shape, cracked kernel ratio (mass ratio of fissured kernels to total head kernels) and cleanliness (Conwey et al., 1991).

Much research has been done to identify the main sources of rice kernel breakage. The causes of kernel breakage can be grouped into pre-milling and milling groups. Pre-milling parameters are those related to varietal, agronomic, and environmental factors and threshing, handling, and drying operations, which are concerned to prior to milling process. Milling parameters are those associated with the milling itself. Immature, fissured, chalky, and softer kernels are weaker and more susceptible to breakage during rice milling and consequently result in a lower HRY (Bhattacharya, 1969; Matthews et al., 1970; Zhang et al., 2005; Jürg et al., 2008).

All conditions affecting the formation and increase in rice kernel weakness fall into the category of pre-milling factors. Delayed harvest and harsh drying conditions are the most important factors responsible for grain fissure and breakage. Moreover, chalky grains have a lower HRY because they tend to be weaker and more prone to cracking and breakage during milling than translucent rice kernels. Chalkiness is a result of environmental and genetic characteristics (Lisle et al., 2000). Harvesting at high moisture levels, adverse weather conditions such as high or low night temperatures, and some agronomic practices increase chalkiness (Webb, 1985; Counce et al., 2005). The moisture content, temperature, and shape of the rice grains affect the compression, tension and bending strengths of the kernels and subsequently their susceptibly to breakage (Ancheta and Andales, 1990; Husain et al., 1971; Kunze and Choudhury, 1972; Prasad and Gupta, 1973; Chattopadhyay et al., 1979).

Climatic conditions during growth, the maturity and moisture content of the grains at harvest, fissuring in rice kernels from mechanical harvesting and drying, and numerous other elements comprise the primary pre-milling factors that affect kernel breakage during milling (Farouk and Islam, 1995; MC Neal, 1950; Biswas et al., 1969; MC Donald, 1967; Matthews et al., 1970). Studies on the factors influencing milled rice breakage indicate that pre-milling parameters are very numerous and complex. The present article reviews and analyzes the effects of pre-milling factors on rice kernel breakage and HRY.

Effect of Varietal Characteristics

Varietal characteristics that contribute to kernel breakage during milling include the ease of bran removal, chalkiness, and kernel shape and hardness (Matthews et al., 1970). HRY significantly correlates with the volume and density of the paddy grain, but negatively correlates with hull percentage (Jongkaewwattana and Geng, 2001). The shape of the rice grain is its most stable varietal characteristic. The thickness of the rice grains do not always increase proportionately with the length of the grain. Longer grains usually have a lower length-to-width ratio than shorter ones, so they are subject to a higher degree of bending stress during milling and break rather easily (Figure 2).

Clement and Seguy (1994) showed that long and thin rice kernels are more prone to breakage during

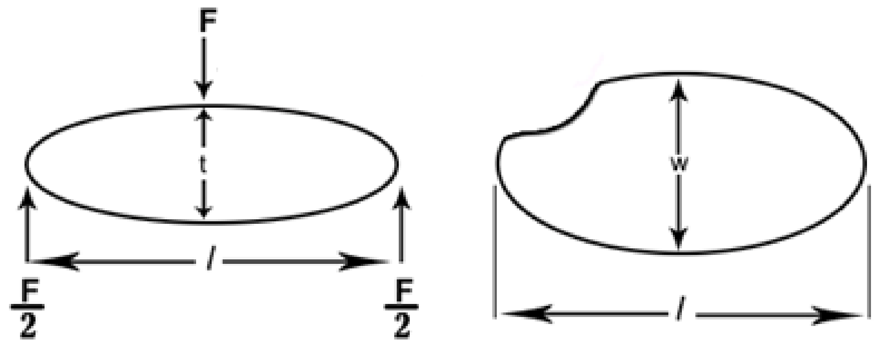

Figure 2 Dimensions of rice grain and forces acting on it through milling action; l= length, t= thickness, and w= width; the bending stress at the center of grain equals to $s = \frac{F.l}{wt^2}$, indicating that longer grains experience more bending stress (Sarker and Farouk, 1989).

milling than wide short kernels. Jongkaewwattana et al. (1993) and Matthews et al. (1970) found that the more rounded and thicker shape of rice grains decreases breakage during milling more than any other factor. A higher percentage of hulls on the long paddy grains are another factor that increases the difficulty of successful milling (Jongkaewwattana et al., 1993).

Short grains flow more easily than long grains through the friction-type milling chamber of rice whiteners, which decreases kernel breakage (Abdur Rahman, 1996). Matthews and Spadaro (1976) found that rice breakage during milling increased as the diameter of the kernel decreased. Sun and Siebenmorgen (1993) showed that HRY increased as thickness increased up to a maximum value, and then decreased. Firouzi et al. (2005) demonstrated that the lowest and highest amounts of broken milled rice were observed for round and long paddy grain varieties, respectively.

HRY is also influenced by the maturity of the cultivar as well as the variety. Geng et al. (1984) showed that HRY decreased when intermediate and late maturing cultivars were replaced with very-early and early maturing cultivars in California.

Effect of Agronomical Practices

Agronomical practices such as plant density, nitrogen application, and water management have also been known to influence quality of milled rice (Dilday, 1988; Jongkaewwattana and Geng, 1991; Perez et al., 1996, Gravois and Helms, 1996). Dilday (1988) found that HRY decreased 7 to 22% in the Lemont variety and 2 to 6% in the Newbonnet paddy varieties when no nitrogen was applied when compared with the application of nitrogen in pre-flood or split applications.

The timing of nitrogen application also affects kernel breakage. Perez et al. (1996) recorded an HRY of 58% high-protein rough rice when nitrogen fertilizer was applied at the flowering stage, but only 47% HRY when nitrogen was applied during the last stage of growth. The positive effect of nitrogen on HRY relates to its significant influence on the protein content of the rice grains (Nangju and De Datta, 1970; Seetanum and De Datta, 1973; Blakeney, 1979; Jongkaewwattana et al., 1993; Cagampang et al., 1966; Jürg et al., 2008). High protein content improves HRY, probably by increasing the packing of a protein matrix between the endosperm starches (Nangjo and De Datta, 1970; Del Rosario et al., 1968). Leesawatwong et al. (2005) stated that HRY is positively correlated with the relative abundance of storage protein in the lateral sections of the endosperm of rice kernels.

Water management is an agronomical practice that can affect the quality of milled rice. Cheng et al. (2003) showed that different water treatments influenced HRY. This was attributed to the grain filling patterns and the quality of final paddy grains. The weight and density of the paddy grains depend on grain-filling during plant growth and has a direct impact on HRY.

Variability in grain size and shape, and non-uniformity in grain maturity adversely affect the quality of milled rice. This indicates that selecting plant cultivars having more uniform grain properties on the panicle will achieve better milling quality (Jongkaewwattana and Geng, 2001).

Environmental Effects

Environmental conditions during growth can cause fissuring of milled rice and decrease HRY (Siebenmorgen et al., 2007). Rice grains are hygroscopic and easily retain or lose moisture in response to the environment (Siebenmorgen et al., 1998). The migration of moisture into or out of the kernel depends on the temperature of the surrounding air and its relative humidity (RH), as well as the moisture content (MC) of the kernels (Kunze and Choudhary, 1972; Brian et al., 1999). When the rice kernel adsorbs moisture, the outer layers swell and compressive stresses are generated in the surface layers. Opposing stresses produced inside the kernel creates tension in the inner cells. If the internal tensile strength is exceeded, fissures will appear in a straight line perpendicular to the longitudinal axis of the kernel (Kunze and Hall, 1965). If the rice kernel loses moisture, and the tensile strength is exceeded, a pattern of fissures will spread across the kernel surface (Kunze and Choudhary, 1972).

The study of Brian et al. (1999) revealed that rice kernels with a high MC recorded higher breakage at low RH and rice kernels with low MC recorded higher breakage at high RH. Similar results were obtained by Siebenmorgen et al. (2007) who recorded fissure formation in milled rice kernels. Their results showed that fissures formed easily at the lowest kernel intermediate moisture content (IMC) (11%) at 90% RH and the highest kernel IMC (14%) at 10% RH. Chen et al. (1983) found that paddy samples at 9.4% MC (db) had lower HRYs at 20°C than at 30°C, but that temperature had no or little effect at a kernel MC of 11.9% (db). This indicates that dryer kernels were more susceptible to breakage with an increase in temperature.

Nighttime air temperature during growth of the rice plant has also been shown to be a negative parameter contributing to chalkiness and a decrease in milling quality (Counce et al., 2005; Laning et al., 2011; Ambardekar et al., 2011). Counce et al. (2005) confirmed a relationship between night air temperature and rice milling quality. They noted that research into developing cultivars resistant to the negative effects of high night temperatures would be useful for rice producers. The increase in chalky rice kernels with an increase night time temperatures has also been a suspected cause of decreased rice milling quality, including HRY.

Effect of Paddy Harvest Time and Method

Harvest moisture content (HMC) is a major contributor to milled rice breakage. Too early and too late harvest lead to arise more immature and cracked kernels, respectively, and subsequently more broken milled rice (Sajawan et al., 1990). Luh (1991) found that, for high quality head rice with maximum HRY, the paddy must be harvested at optimum MC. They found the optimum HMC for seven US paddy varieties to be 6.0% to 21.5%, db (Jodari and Linscombe, 1996). Davis (1944) reported that optimum HMC for the Caloro rice variety was 20 to 24%. Siebenmorgen et al. (2006) determined HMC to be 19-22% for two long grain paddy varieties and 22-24% for a medium grain variety.

Ntanos et al. (1990) concluded that there is an optimum harvest time for each of five paddy varieties investigated to achieve the highest total milling yield with lowest grain breakage. It was reported that harvesting at 27 d to 39 d after flowering at high MC (18-23%) resulted in the highest head rice recovery in India. Harvesting before or after that period increased the incidence of broken grains (Grovindaswami and Ghosh, 1968). In Japan, 20 to 25 days after heading was found the best harvest time (Eikichi, 1954). Surek and Beser (1998) in Turkey showed that the maximum milled rice, minimum breakage, minimum unfilled and partially filled grains, and minimum chalky kernels were obtained at 49 d after flowering. The early harvesting of rice caused both quantitative and qualitative losses. Firouzi and Alizadeh (2013) showed that the highest (57.91%) HRY mean value was obtained at the 30 Days after fifty percent flowering. Earlier and later HTs had significantly less HRY (Figure 3).

Harvesting method also affects HRY. It has been reported that combine-harvested samples recorded 5% more broken kernels than samples harvested manually (Matthews and Spadaro, 1975). Fliz et al. (2005) tested the Cocodrie variety

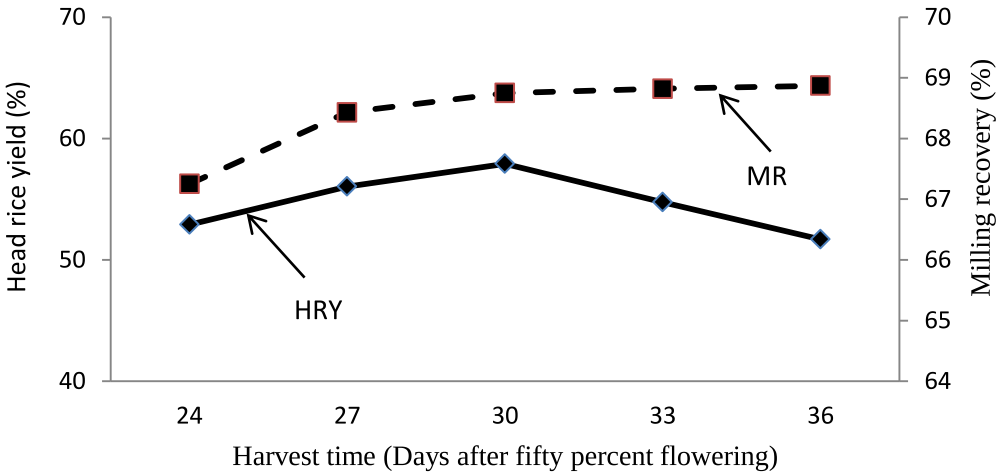

Figure 3 Effect of harvest time on head rice yield and milling recovery (HRY & MR, respectively) (Firouzi and Alizadeh, 2013).

harvested at three cylinder speeds on a combine harvester and found that increasing the cylinder speed significantly increased the percentage of damaged kernels. Parker et al. (2007) found that the Case combine harvester produced significantly more damaged rice than the John Deere at 13 and 16% HMC, but not at 20%. Alizadeh and Bagheri (2009) indicated that the threshing method has a significant effect on the percentage of broken and hulled paddy rice. The least kernel damage was observed from the power tiller operated thresher and most kernel damage was observed from the cereal combine harvester.

Effect of Drying and Parboiling

Drying is a thermo-dynamic process wherein moisture is removed from the rice by differences in vapor pressure between the grain and the ambient air. Drying can also be done by evaporative cooling (Anwarrul et al., 1997). At high moisture levels, the husk is more firmly attached to the kernel and does not easily split; more stress is needed to husk wet paddy grains.

Drying of the grains is required prior to milling. This process generates moisture and temperature gradients in the kernel, which increase tensile stress at the surface and compression at the core (Sharma and Kunze, 1982). When the tensile strength at the kernel surface is exceeded, fissures form (Kunze and Choudhary, 1972). Improper drying is a major cause of fissuring in rice kernels and leads to kernel breakage during milling.

Peuty et al. (1994) reported that paddy-drying conditions affect rice breakage during milling so that rice breakage increased rapidly as the MC of the drying air decreased. A quick rate of moisture removal also decreased milling output (Abdur Rahman et al., 1996). Farouk and Islam (1995) reported that crack generation in dried grains was dependent on the drying air temperature and inversely on the final MC. Increasing drying air temperature, increased the number of cracked grains, but crack generation decreased as MC increased.

Parboiling rough rice prior to milling is strongly recommended to improve the mechanical strength of fissured paddy kernels. It has been found that parboiling can decrease breakage during milling to essentially zero (Matthews et al., 1982). Parboiled rice constitutes ≈15% of the world's milled rice (Bhattacharya, 2004). Parboiling is practiced in India, Bangladesh, Pakistan, Myanmar, Malaysia, Sri Lanka, Guinea, South Africa, Italy, Spain, Thailand, Switzerland, USA and France (Pillaiyar, 1981). In India and Bangladesh about 60 and 90%, respectively, of total rice production is parboiled (Choudhury, 1991).

Parboiling is a hydrothermal treatment usually followed by drying before milling. It consists of soaking, steaming and drying (Figure 4). This process fills the void spaces and cements the cracks inside the endosperm, making the grain harder and minimizing internal fissuring and breakage during milling (Kaddus et al., 2002). Starch gelatinization is responsible for the attributes of parboiled rice (Marshal et al., 1993). Improvement in the quality of milled rice from parboiling is well known (Bhattacharya and Subba Rao, 1966; Priestley, 1976 a ; Juliano et al., 1981; Itoh et al., 1985; Marshall et al., 1993). Raw paddy grain milling produces more broken kernels than parboiled paddy grain milling because of the softness of the kernel (Anwarrul et al., 1997). Itoh et al. (1985) stated that the crushing hardness (stress applied to crush a kernel) of parboiled brown rice increased owing to the viscoelasticity of kernel resulting from gelatinization that takes place at 100°C during steaming.

Effect of Rough Rice and Ambient Air Conditions during Milling

The MC of rice has a strong influence on milling quality. MC that is too high or too low seriously affects milling outturns. Ancheta and Andales (1990) showed that the bending strength of rice grains is inversely related to MC. At MCs of 12-16%, the grains at lower MCs were more resistant with higher bending strength. Because there is a high correlation between bending strength of rice kernels and HRY, high MC during milling decreases HRY (Lu and Siebenmorgen, 1995). Alizadeh et al. (2011) showed that the breakage force of paddy and brown rice increased as the paddy grain MC decreased after drying, resulting in higher HRY.

Laboratory studies performed by Zhang et al. (2002) indicated that the fracture energy of rice kernels increased fairly linearly as drying time increased (or MC decreased). The fracture strength and elastic modulus also increased as MC decreased. Researches have shown that the quality of milled rice, including HRY, increases as MC decreases. Stipe et al. (1971) showed that the quality of milled rice is low when paddy grains with high MCs are hulled. The percentage of broken brown rice grains increased during milling with a rubber roller husker as the MC increased (Firouzi et al., 2010).

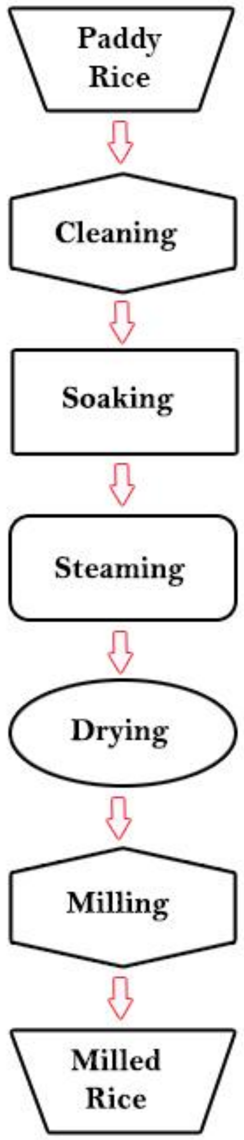

Figure 4 Principals of rice parboiling process.

Pominski et al. (1961) tested samples of Bluebonnet 50 long-grain rice at MCs of 10 to 14% and concluded that for each one percent decrease in MC, head yields and total yields increased 3% and 0.7%, respectively. Firouzi and Alizadeh (2013) found that milled rice breakage (MRB) and cracked kernels ratio (CKR) of the Hashemi cultivar increased as the MC of rough rice increased (Figure 5). A similar trend was reported by Ancheta and Andales (1990). They noted that higher values of total yields and head yields for milled rice were achieved at lower MCs of 12% (wb.). When using a commercial rubber roll huller (Satake Co. Ltd, Japan), the average percentage of broken kernels increased as paddy grain MC increased from 8-13%

(Juma Omar and Yamashita, 1987). Dilday (1987), however, demonstrated that rice breakage decreased as paddy grain MC increased from 12 to 16%, which contradicts the findings of other researchers.

Ambient RH and the difference between air temperature and the rough rice also affect the performance of milling systems. Autrey et al. (1955) showed that, as the difference between rough rice and ambient air temperature increased, the effectiveness of the rice milling system decreased. They also found that the RH of the milling environment had a significant effect on the PMR.

Conclusions

A review of the literature indicates that a number of pre-milling factors contribute to rice kernel breakage during milling. It was confirmed that decreased mechanical strength of rice grains against stresses during milling is the main cause of breakage. Fissures, chalkiness, inherent softness of some paddy varieties, and the lower bending strength of longer grains are major contributors to the mechanical weakness of paddy grains.

These findings indicate that increased precision during production and the use of more resistant paddy kernels strongly influences the quality of milled rice. Varieties with low chalkiness and proper application of nitrogen at the growth stage of the rice plant, harvesting at optimal times, the use of suitable harvesting and threshing equipment at precise settings, and appropriate drying procedures for rough rice can minimize milled rice breakage.

Parboiling raw paddy grains can also minimize fissuring in rice kernels and subsequently decrease breakage during milling. However, the energy consumption and economical aspects of parboiling in industrial scale are topics which need to be studied more at the future. Considering the multiplicity and complexity of the varietal and engineering pre-milling factors affecting rice breakage, future study is required.

Acknowledgments

The author is grateful for the funding supplied by the Rasht branch, Islamic Azad University.

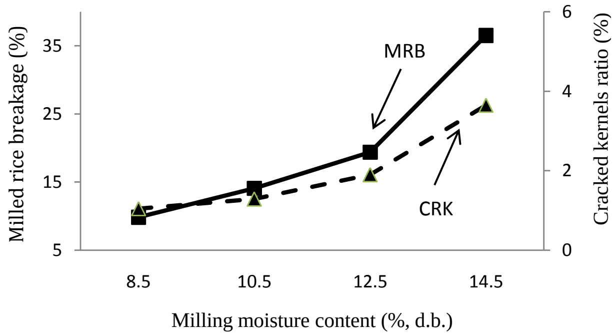

Figure 5 Effect of milling MC on milled rice breakage and cracked kernels ratio (MRB & CRK, respectively). (Firouzi and Alizadeh, 2013).

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Manuscript received 4 August 2014, accepted 20 November 2014