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Causes for breakage of rice during postproduction handling: A review

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Abstract
Rice (*Oryza sativa* L.) is one of the most important cereals in the world. Before it is consumed, it is common to remove the hull, bran and germ from the rough rice kernel which is either parboiled or not. During such processing, rice kernels are subjected to mechanical stresses which cause some rice grains to break. A main challenge of the rice industry is to minimize the quantities of broken rice. Here review the factors impacting the breakage of rice kernels. Their tendency to break is primarily determined by fissures and rice kernel dimensions, properties which are both cultivar and rice grain history dependent. The intensity of processing of any given rice determines the actual level of broken rice kernels. If performed properly, parboiling, a three-step hydrothermal treatment consisting of soaking, heating and drying of rough rice, substantially reduces the level of broken kernels.

Keywords: Fissures, milling quality, degree of milling, head rice yield

1. Introduction
Rice needs the utmost care during post-harvest handling and processing, as it is consumed as a whole kernel. The surrounding environment greatly affects its quality, especially the head rice yield (HRY). The economic importance of maintaining a high HRY is critical during drying, storage, and milling operations (Sharma and Kunze, 1982) [10]. Inadequate quality control measures during any of the aforementioned steps can result in fissuring which de-creases the yield of milled rice. Fissured milled rice kernels cause great financial losses to post-milling processors in terms of both product waste and processing plant production limitations. Quantifying the rates of fissure formation in rice kernels at all stages of rice milling, transport, and end-use processing is necessary to design equipment and implement procedures to minimize fissure formation. Dehulling of rough rice separates the hull from the brown rice. The most common dehuller makes use of rubber rolls. In such dehuller, rough rice is fed in a continuous stream at a controlled rate between two rubber rolls rotating at different speed in opposite directions. Because each side of the rough rice attempts to travel at the same linear speed as its corresponding roll, the hull is sheared from the resultant brown rice. Milling of brown rice kernels involves removing the bran and germ from the underlying endosperm by applying friction and/or abrasion forces. In abrasive milling, a high-speed rotating stone with a rough surface abrades off the bran. In contrast, in friction milling, the rice grains are forced against each other and against a metal screen by a steel-ribbed cylinder rotating inside a metal-plated cylinder. As a result, bran is removed by frictional forces created between individual rice grains on the one hand and between rice grains and the metal screen surface on the other (Delcour and Hoseney, 2010) [11]. The transaction price of rice has been strongly correlated to the size and shape, whiteness and cleanliness of the rice (Conway, Sidik, & Halid, 1991) [12]. Fallowing is a review based on research papers published, depicting the causes for breakage of rice at different stages of post-production handling of paddy.

2. Harvesting at different stages
Phetmanyseng *et al.*, (2019) [2] conducted work in Cambodia, examined the effect of harvesting time during ripening and drying method prior to milling. Crops were planted around June, temperatures remain similar to maturity is termed as wet season (WS). In contrast, in the dry season (DS), planting takes place in the coldest time of the year (January) and temperatures gradually increase during the season of April/May when the crop is harvested under very high daily mean temperatures exceeding 30 °C.

There were five experiments conducted to examine the effect of harvesting time during ripening (Experiment 1, 25 June 2014, Experiment 2, 10 January 2015, Experiment 3, 15 January 2016, Experiment 4, 28 June 2016, Experiment 5, 5 January 2017). In Experiments 1, and 3, harvesting time spanned 25, 30 and 45 days after 75 % flowering. Experiments 4 and 5 were harvested at 25, 30 and 35 days after flowering. Drying methods such as flat bed dryer, sun drying with a tarpaulin sheet and sun drying with nylon net were used. Measures of milling quality determined. Temperature was generally higher in the DS than in the WS, but DS temperature varied among the 3 years of testing. When an artificial dryer was used in Experiments 2 and 3, Head rice recovery was much higher between 47 % and 52 % at 25 days after flowering and this decreased to 34–36 % and 8–17 % at 35 and 45 days after flowering, respectively. In Experiment 4, there was no significant effect of treatments on brown rice, but milled rice decreased when harvest was delayed to 45 days after flowering. There was a sharp increase in broken rice with the delay in harvest time after 25 days after flowering and also broken rice increased greatly with sun drying compared with the flatbed dryer. In Experiment 5 When rough rice was sun dried on tarpaulins, head rice recovery decreased from between 27–37% down to 7–8% as harvest was delayed from 25 to 45 days after. Milling after 2 or 10 days after drying had almost no effect on milling quality.

It is concluded that rice crops should be harvested in both DS and WS around 25 days after 75% flowering. If an artificial dryer is not available, rough rice should be sun dried only in the morning with frequent stirring and mixing to promote more even drying.

3. Combine vs Hand harvesting

Matthews *et al*., (1981) [1] harvested five lots of long-grain rough rice (Star bonnet variety) by a combine. The samples were brought to a room maintained at about 22.2 °C and 60 percent relative humidity and spread on screen-bottom trays. In each field a plot about 1.2 x 9.2 m adjacent to a combine-harvested plot was cut by hand, were threshed by hand-stripping the kernels from the straw. All the samples were dried on screen-bottom trays to about 12.5 percent moisture. A portion of each hand and combine-harvested sample was cleaned and then separated by rough-rice kernel thickness into four fractions by passing the rice over appropriate oscillating slotted screens. The ranges of kernel thickness for the four fractions were: 1.63 to 1.78 mm, 1.78 to 1.93 mm, 1.93 to 1.98 mm, and 1.98 to 2.29 mm. Rough-rice kernels with a thickness of less than 1.63 mm were not used because they were immature. As controls, a portion of each hand-and combine-harvested rice sample was cleaned, and the kernels less than 1.63 mm thick were removed. Thus, the range of kernel thickness for the unfractionated controls was 1.63 to 2.29 mm. Twenty-five-gram samples of each of the rough-rice-thickness fractions and controls were spread in a mono layer under an X-ray film and exposed for 1 min in a General Electric grain inspection unit. The developed X-ray films were examined for cracked and broken kernels. For broken kernels there is a clear separation of the two pieces of the kernel on the X-ray film. Cracked kernels have only a fine line crossing the kernel to indicate the position of the crack. It is unknown what percentage of cracked kernels is detected by the X-ray technique. Breakage values reported are the sum of the cracked and broken kernels as a percent age of the total number of kernels. Hand-harvested lot had practically zero breakage it is possible that hand harvesting did not break any grains. In combine-harvested rice, five out of six lots the breakage in the rough rice was greater in the thickest and the thinnest fractions than it was in the fractions of intermediate thicknesses. It is concluded that minimum breakage occurs in kernels of intermediate thickness.

4. Different sun drying methods

Imoudu *et al*., (2000) [3] Parboiled a portion of the harvested crop. Equal samples of parboiled and non-parboiled rice were evenly spread at 5.6 kg/m^2 and dried on concrete floors and on mats (made from agricultural by-products). The samples were allowed to dry to 10%, 12%, 14% and 16% moisture. Each sample was milled separately after the moisture content reading. The percentage yield increased when the rice was parboiled. This might have been due to the parboiling process improving the shear properties of the paddy. But paddy dried on a concrete floor took a longer time to attain the desired moisture content than did that dried on a mat. Drying on a concrete floor tended to favour a higher percentage yield than drying on a mat. The method of drying significantly affected milling yield at 0.01 level. Percentage of broken grains was as low as 34% for parboiled rice and 48% for non-parboiled rice. Best results in terms of percentage of broken grains were obtained at 12% and at 14% moisture content in the treatments.

5. During storage

Yubin lan and Kunze (1996) [4] Equilibrated rough, brown, and milled rice samples to 46, 62, and 80% equilibrium relative humidities (erh). Equilibrated rice samples were placed inside an airtight Plexiglas chamber and exposed to environmental conditions produced with saturated sodium nitrite solutions (65% rh), saturated potassium chromate solutions (86% rh), and water (100% rh). Fissure responses corresponding to the exposure conditions were observed. The rice was inspected and the fissured grains were noted. Rice Fissuring Experiments Cumulative percentage of fissured grains (CPFG) was obtained. The indicated the high potential for the development of stress fissures when any form of low moisture rice is subjected to high humidity conditions. As the exposure rh was increased, a greater percentage of multiple-fissured grains were produced. The difference in CPFG among rough, brown, and milled rice showed that the husk had significant influence on the rate of moisture adsorption. The husk, as a physical barrier, reduced the amount of water available for diffusion through the bran into the endosperm. Due to the husk or bran, the rates of adsorption for rough rice and brown rice in a given environment were reduced, as well as the potential to fissure. The accumulated moisture caused the surface layers to expand, producing compressive stresses which in turn induced tensile stresses at the center of the grain. Rapid moisture adsorption by low-moisture rice may cause the grains to fissure. A single grain may develop a partial fissure, or perhaps several large fissures depending on the intensity of the water activity (moisture adsorption). However, from the experimental observations with the magnifier, most fissures were not completely through the cross-section of the grain. The initial moisture content or erh (equilibrium relative humidity) had a remarkable influence on stress fissure development. Rough rice at 46% erh had 49%

fissured grains after the 12 hr of exposure to 100% rh. At 62% erh, the CPFG decreased to only 29% after the 12 hr of exposure. Furthermore, no grains were fissured when rough rice at 80% erh was exposed to 100% erh.

6. Parboiling

Bhattacharya (1969) [6] Paddy varieties when milled 7.7 mm, three 5.6mm and 5.1mm in length were selected, manually harvested, threashed and one variety is field dried and rest dried in shade. All paddy samples (raw and parboiled) contained 11 to 12.5% moisture (wet basis) at the time of milling. All paddy samples shelled in a McGill sheller milled in a McGill miller No. 1 with moderate manual pressure. Broken percentage was evaluated in two ways brokens were separated after shelling and other was fed as it is to polisher. When fed as it is at zero, 2.8, 4.9, 7.1 and 9.7 % degree of milling (DOM) percentage brokens were 15.4, 16.4, 17.0 and 23.9 % respectively. When fed after removal of brekens at 2.8, 4.9, 6.5 and 9.9 % DOM percentage of brokens were 1.2, 1.6, 2.0 and 8.1 respectively. It can be learnt grains remaining unbroken after shelling gave little breakage when separated and milled. That the breakage was mostly related to that the cracked and immature whole kernels. Effect of parboiling on breakage was studied. All samples were shade-dried after parboiling to preclude any strain during drying. All the lots gave very low or negligible brokens after parboiling. As further evidence, a portion of the first variety was subjected to both over drying and wetting to induce extensive cracking (as was also reflected in very severe breakage), and then parboiled. The dramatic restoration of milling quality left no doubt that any type or extent of cracking was healed by parboiling.

7. During hulling

Alsharifi *et al*., (2017) [5] Removed husk from paddy grain by using Satake type machine and Yammer type machine at three grain moisture levels (10–12%, 12–14% and 14–16%) and at three clearance levels 0.4, 0.6 and 0.8 mm. And are considered for the test cracked grain percentage, brown rice percentage, husking efficiency, head rice percentage and broken rice percentage. The results indicate that the increasing the clearance between cylinders leads to decrease the cracked grain percentage, and As for the increasing the grain moisture leads to increasing of the cracked grain percentage, and the results are 4.238, 5.539 and 5.723% respectively. This is due to the fragility of the rice grains and increasing the pressure, this leads to increase the percentage of cracked grain with grain moisture increase. At clearance between cylinders 0.4 mm has the highest husking efficiency of 84.490%, and clearance between cylinders 0.8 mm has the lowest husking efficiency of 81.764%. As for the increasing the grain moisture leads to decreasing of the husking efficiency. The best results of husking efficiency is 87.936% have come from the triple overlap among Satake type machine, grain moisture 10-12%, and clearance 0.8 mm. Increasing the clearance between cylinders leads to increase the percentage of head rice, Because increasing the percentage of breakage with the de-creasing clearance between cylinders and reflected negatively on the ratio of head rice. As for the increasing the grain moisture leads to the decreasing of the percentage of head rice.The grain moisture content 10-12% superior significantly on the two levels 12-14%, 14-16% and the clearance between cylinders 0.8 mm superior significantly on two clearance 0.4 , 0.6 mm in all studied properties. The best results have come from the triple overlap between Satake type machine, grain moisture (10-12%), and clearance 0.8 mm. However the Satake type machine is significantly better than the Yanmar type machine. This is due to the efficiency and engineering design of the machine and finishing the works with less time as compared the Yanmar type machine.

8. During milling

Abozar *et al*., (2014) [7] Selected two most cultivated cultivars of long-grain Iranian rice (Tarom and Fajr). Unparboiled samples were dried in a standard hot air oven at 35–40 °C for up to 24 h and different time intervals, until achieving 12%, 10% and 8% of moisture content. Two-thirds of the collected samples were parboiled with three soaking temperatures of 25 ºC, 50 ºC and 75 ºC and three steaming times of 10, 15 and 20 min. The parboiled samples were then dried by leaving on the mats for 48 h until the moisture content reduced to 15% then dried in a standard hot air oven at 35–40 °C for 24–48 h to achive 12%, 10% and 8% of moisture content levels. The sample with initial soaking temperature of 25 °C and steaming time of 10 min was given the label of 25-10. Similarly 25-15, 25-20, 50-10, 50-15, 50-20, 75-10, 75-15 and 75-20. Dehusked using a laboratory rubber roll type rice husker and subsequently were milled for 30 s at room temperature using a laboratory friction and abrasion vertical type whitener (VP-31, Yamamoto, Japan). The milling pressure was adjusted to 300 g/cm^2. During whitening (milling) of the kernels, the milling pressure was kept uniformly for all the samples. The head rice and broken kernels were separated using a laboratory rice grader. The degree of whiteness of milled rice samples was measured with a laboratory whiteness meter (C-300-3, Kett Electronic, Japan). Milling recovery was higher for Tarom than that for Fajr in all levels of moisture content. The values of MR decreased with increasing moisture content from 8% to 12%, for both parboiled and unparboiled samples. Head rice yield (HRY) increased with the decrease in moisture content from 12% to 8% for both parboiled and unparboiled grains. The highest and the lowest values of HRY for parboiled Tarom and Fajr were found both in samples 25-20 and 50-10, respectively. That parboiling caused 14.3% and 10.0% increase of HRY compared to unparboiled Tarom (51.5%) and Fajr (47.0%) varieties in the same level of moisture content. Degree of milling was 12.7% and 13.0% for their unparboiled samples, respectively (both at 12% moisture content). After parboiling, the DOM values of the two varieties decreased, the maximum obtained values of DOM for parboiled Tarom and Fajr varieties were 6.1% and 6.2%. For parboiled Tarom and Fajr, the lowest DOM was obtained as 4.8% and 5.0%, respectively, in the cases of 25-20, 75-20 samples, both at moisture content of 8%. Whereas for unparboiled Tarom and Fajr, the lowest DOM was achieved as 9.7% and 10.2%, respectively. DOM increased with increasing moisture content for both varieties. When moisture content increased from 8% to 12%.

Reid (1998) [8] Four long-grain rice cultivar harvest at different moisture content were Alan-23%, Alan-19%, Lacassine-21%, Newbonnet-19%, and Millie-21%. Immediately after harvest, foreign matter was removed. And dried in a tray drier. Subjected to Four drying air conditions involving relative humidity and temperature produced varying drying rates. First two represent air conditions corresponding to an equilibrium moisture content (EMC) of 8.6%, and second two correspond to an EMC of 6.3%. Two samples were removed at each 15-min interval up to 1 hr and at each 1-hr interval up to 4 hr. (15, 30, 45, 60 min, 2, 3 and 4 h). After removal from the drying chamber, the samples were allowed to slowly dry (i.e., over a period of four to six days) to ≈12.5% moisture content (MC) in another conditioning chamber. Another control sample dried with air at 33.0 °C and 67.8% rh; corresponded to an EMC of 12.5%. Rough rice subsamples were hulled in a McGill laboratory huller with a clearance of 0.048 cm. The brown rice was then milled in a McGill no. 2 mill. Samples were milled for either 15, 30, 45, or 60 sec to produce varying milled rice yield (MRY), head rice yield (HRY), and degree of milling (DOM) values. DOM of the head rice was measured using a milling meter, Satake model MM1-B. The milling meter displays DOM as a value from 0 (for brown rice) to 199 (for pure white rice). DOM levels of 85–95 are target levels for most commercial rice mills. The MRY and HRY data from each air condition duration drying treatment were linearly regressed against the corresponding DOM. This implies that as rice is milled to greater extents (higher DOM), the HRY decreases linearly. Within the bounds of the experimental levels tested, neither the drying air condition nor drying duration affected the rate at which HRY changed with DOM. The MRY slope represents the removal rate of bran, and possibly some endosperm, while the HRY slope also includes the loss of brokens. However, the cultivar and the moisture content at which the rice was milled significantly ($p<0.05$) influenced this rate. At higher milling moisture contents, the decrease in HRY per unit of increase in the DOM was greater than at lower moisture contents. While not conclusive, there was an indication of a relationship between the average kernel thickness of a cultivar and the HRY versus DOM slope. When the HRY and MRY data were combined and included as a model term, the final model was which included cross terms for cultivar and yield type (MRY or HRY) as well as milling MC and yield type. which indicates that the relationship between milling slope and milling MC depends on the cultivar and the yield being considered. The relationship between milling slope and milling MC suggests that as milling MC increases, the bran layers are more easily removed. At higher milling moisture contents, the decrease in HRY per unit of increase in the DOM was greater than at lower moisture contents.

Afzalinia *et al*., (2006) [9] Carried out study in three different parts. In the first part, comparison between the rubber roll sheller and friction whitener as a sheller from the viewpoint of the shelling performance and rice breakage was conducted in the province of Gilan. Safidrood a rice variety with dimensions of 10.60 mm length, 2.35 mm width, and 2.00 mm thickness at 6% moisture content (wb) was used. In the second part was carried out in the province of Fars. Three levels of paddy moisture content (8 to 10%, 10 to 12%, and 12 to 14%) were considered. A rubber roll sheller, an abrasive whitener, and a friction whitener as polisher was used. A local rice variety (Kamfiroozi) with dimensions of 5.9 mm length, 2.32 mm width, and 1.78 mm thickness was utilized. a rubber roll sheller, an abrasive whitener, and a friction whitener as polisher was used. The paddy with the selected moisture content was passed through the milling system and samples of 100 g were taken from the outlet of each machine to measure the percentage of rice breakage by the milling system. In the third part, four different combinations of whitener and polishers in the milling system were compared from the viewpoint of rice breakage, Considered combinations were:

1. Three abrasive type whiteners in series and a rubber brush polisher.
2. Three abrasive type whiteners in series and a friction type whitener as a polisher.
3. Two friction type whiteners in series without polisher.
4. Four abrasive type whiteners in series without polisher.

The same sheller, paddy separator, and cleaning and grading systems were used for all treatments. An identical amount of rough rice (160 kg) with 12 to 14% moisture content was whitened by each of the considered milling systems and 100-g samples were taken from the outlet of each system. Broken kernels of the samples were separated from the whole ones and finally the breakage percentage of each treatment was calculated. The amount of breakage resulting from the use of the friction whitener as sheller was approximately twice as much as that of the rubber roll sheller. While its shelling performance was only 8.7% higher than that of the rubber roll sheller. Even though, the shelling performance of the friction whitener was higher than that of the rubber roll sheller, using it as a sheller is not recommended because of its high percentage of rice breakage. The minimum total rice breakage occurred at the range of 12 to 14% moisture content; The results also revealed that about 75% of the total rice breakage during the milling process occurred in the whitening machine. The minimum total rice breakage occurred at the range of 12 to 14% moisture content; therefore, this range was the optimum moisture content for the paddy at the milling time. Results of this study showed that the milling method had a significant effect ($p<0.01$) on the rice breakage during the milling process. The method containing a friction type whitener had the highest amount of rice breakage, and the treatment using the abrasive whitener without polisher had the lowest breakage; The results of the rice appearance comparison showed that the output of the treatment using three abrasive whiteners in series and a friction whitener as polisher had the best appearance. The economic evaluation also showed that the system containing three abrasive whiteners in series with a friction whitener as polisher was the most inexpensive method to whiten a unit weight of paddy.

Bautista and Siebenmorgen (2002) [8] Evaluated performance of three laboratory mills (IRRI Test Tube Mill, Kett "Pearlest" Polisher, and McGill No. 2 Mill). A laboratory mill that would adequately provide an indication of milling quality "small" samples. Rice samples from breeding lines, ranging from approximately 2.5 to 10.0 g, or even smaller samples obtained from single or multiple panicles are examples of "small" samples. The International Rice Research Institute (IRRI) Test Tube Mill utilizes an abrasive compound (aluminum oxide) and milling is accomplished by vigorously oscillating tubes containing small samples of rice. Milling was influenced by the frequency and length of tube oscillation. Milled rice is separated from the bran and aluminum oxide by using a sieving screen (No. 20). The Kett "Pearlest" Polisher is a mill designed for small sample sizes that utilizes centrifugal action to force kernels against a rubber surface to cause removal of bran layers. Centrifugal mills such as the Kett polisher provide a more aggressive means of milling small samples. The McGill No. 2 Mill is a batch type friction mill. It consists of a milling chamber consisting of a rotating shaft with two lobes, a perforated concave and cover, a lever with a counter weight for adjusting pressure in the milling chamber, and a pressure cover. This evaluation typically starts with 150 to 162 g of dried (12% m.c.) rough rice, which is typically dehulled before milling. factors that affect milling include sample moisture content, milling duration, initial temperature of the brown rice. Two rice varieties, 'Bengal' (medium–grain) and 'Drew' (long–grain), were harvested with a plot combine from the University of Arkansas Rice Research and Extension Center at Stuttgart, Arkansas at approximately 18% m.c. (wet basis). Two lots of each variety were dried gently in an environmental chamber; one to 12% and the other to 15% m.c. Each lot was cleaned using a dockage tester (Precision Size Tester, Model XT4 Carter Day Co., Minneapolis, Minn.). After cleaning, samples were sealed in Ziploc bags and stored at 4°C. Brown rice was prepared for each milling paddy by a laboratory huller (Satake Rice Machine, Type THU, Satake Co., Hiroshima, Japan) with 0.48–mm clearance between rollers.

Milling with the IRRI Test Tube Mill was performed by filling each tube (12 mm in diameter and 75 mm long) with 3 g of brown rice mixed with 4 g of aluminum oxide and placing it on the tube holder. The two tube holders were then secured in the oscillating arm of the mill. The samples were run on the mill at durations of 10, 20, 30, 40, 60, 120, and 180 min. After milling, samples were cleaned using screen size No. 20 (Central Scientific Co., Chicago, Ill.) to separate the bran from the milled rice. Milling with the Kett Polisher was performed by filling the milling chamber with 10–g brown rice for milling durations of 10, 30, and 50 s. Milled rice was removed from the collecting pan at the end of each milling run. Cleaning the milled rice samples using a sieve was not necessary because the Kett Polisher is equipped with a vacuum device for separating the bran from the milled rice. The McGill No. 2 Mill was warmed up before running each experiment. This task was accomplished by milling two loads of 120 g of brown rice that were discarded. Milling durations were 10, 30, and 50 s. A 1500–g mass was placed on the mill lever arm, 150 mm from the center of the milling chamber. It was not necessary to use the sieve to separate the bran from the milled rice because the McGill mill has a perforated screen that separates the bran during milling. The milling evaluation was primarily based on the percentage weight of bran removed and the percentage whole kernel yield (WKY).The milling evaluation was primarily based on the percentage weight of bran removed and the percentage whole kernel yield (WKY). The milling effect of each milling on the shape and size of kernels was compared and analyzed using a Satake image analysis system and a video microscope. For all mills, the percentage of bran removed increased with milling duration and sample moisture content. Whole kernel yield (WKY) generally decreased with milling duration. Also, WKY decreased with an increase in sample moisture content. The reduction in kernel dimensions was affected by mill type, milling duration, sample moisture content, and, to a lesser degree, variety. The Kett Polisher tended to chip off kernel ends, which caused a higher reduction in length and adversely affected the integrity of the kernel. Longer milling durations were required with the IRRI Test Tube Mill to attain desired bran removal. Although this mill produced an extremely high WKY, it may not represent the samples' true HRY due to the very gentle milling action employed. However, it could give indications of the HRY potential of a small sample. Because they use a gentle milling actions the IRRI Test Tube and McGill mills maintained the integrity of the kernel endosperm, which made them highly suitable for milling samples for subsequent analysis.

9. Conclusions

One of the main reasons for rice kernel breakage is the presence of fissures. These develop as a result of MC gradients created during rice grain handling, i.e. cultivation, harvest, drying and storage. Both moisture adsorption and desorption can induce kernel fissuring. Besides fissures, kernel dimensions impact HRY. There is, however, still much to be learned on how both phenomena impact HRY. Although much research has been performed on MC gradients and their significance for rice kernel fissuring, hypotheses are often based on computational predictions and should be further validated. In rice dehulling and milling, the level of broken kernels is largely determined by the intensity of processing and the intrinsic rice grain properties. However, as different methods are used to determine HRY and HRY is influenced by the DOM, it is difficult to correlate literature data. If parboiling is carried out properly, it can increase HRY of any rice given feedstock. Critical parameters seem to be the extent of starch gelatinization and kernel fissuring. There is, however, still much to be learned on how both phenomena impact HRY.

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