Breakage of Rice during Milling, and Effect of Parboiling

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ABSTRACT

Several factors are recognized as contributing qualitatively to breakage of rice during milling. The relationship of kernel defects to breakage was investigated in laboratory studies. Most of the breakage in a lot occurred at the earliest stage and increased little with continued milling; it was related quantitatively to the amount of cracked and immature kernels, as revealed in transmitted light. Whole grains showed practically no breakage after milling. These facts indicated that it was primarily the defective grains which ultimately failed in milling.

The well-known improvement in milling quality of rice after parboiling was also related to the above phenomenon. Cracks (whether inherent or freshly induced), immaturity, and chalkiness in the kernels were completely eliminated after the process. Consequently, the milling quality of parboiled paddy was always determined *de novo*, independently of the previous history or condition of the lot, and was always excellent, given proper drying. Parboiling was, therefore, an excellent tool for salvaging any paddy that had been improperly harvested or dried or inadvertently damaged, or paddy that contained a large proportion of immature kernels. Milling quality of damaged parboiled paddy also could be restored by reparboiling.

Several factors are generally recognized as probable causes of breakage of rice during milling. Cracking or checking of the kernel is known to be one factor, since delayed harvesting and threshing (1,2,3) and too rapid drying (3,4,5) – conditions favoring cracking – always increase the number of broken grains. Immature and chalky kernels also are considered to break relatively easily. Moisture content (6) and infestation (7) likewise appear to be contributing factors; also, shape and hardness of the kernels, since long-grain and soft varieties are usually believed to be more susceptible to breakage than short-grain and hard varieties. On the other hand, the type and design of the milling equipment also may influence milling results. Autrey et al. (8) showed that rice breakage was related to milling conditions, particularly the prevailing relative humidity and temperature and the extent of milling. Although there is general awareness about these factors among millers and researchers, quantitative data on many of them are lacking, and little documented evidence exists about their relative importance and precise relationship.

The situation is similar with respect to parboiling and its effect on milling quality. The process is well know to reduce rice breakage (9), but the factors are not well understood. The improvement is usually attributed to either greater hardness of the parboiled grain or to healing of cracks (10,11) and other defects (11), but quantitative data are lacking. The precise extent of benefit resulting from parboiling also is not well established. Data of different workers vary in this respect (compare ref. 9,10,12,13), perhaps because the nature of the improvement process is not fully understood.

Clearly, controlled, systematic experiments to identify and quantitatively evaluate the various factors and their relationship would be of value to the industry.

The following experiments were originally undertaken to examine whether parboiling could restore milling quality to artificially damaged paddy[1]. The results not only were positive, but also demonstrated the striking relation of rice breakage to kernel quality. This led to a detailed laboratory study of the precise relation of various kinds of kernel defects to breakage of rice during milling and the nature of improvement after parboiling.

MATERIALS AND METHODS

Paddy

Several lots of paddy were used. One lot of Coimbatore Sanna (designated Field CS, short for field-dried Coimbatore Sanna) was a commercial sample; in India, it would have been field-dried, that is, manually harvested at a late stage and dried on the stubble for a few days and then in the open yard with or without shocking – conditions conducive to checking of the kernels (1,2,3). One lot of SR-26B (Field SR) and one of Taichung (Native) 1 (Field TN), known to have been harvested and dried as above, were procured from a breeding farm. Another lot of Coimbatore Sanna (designated Shade CS, short for shade-dried CS), Halubbulu (Shade HB), and Bangara Sanna (Shade BS) was obtained from private farms, harvested, and immediately threshed under personal supervision at a high-moisture stage (21.0, 21.7, and 23.6% moisture, respectively) and then air-dried in the shade. All lots were stored in the laboratory in jute sacks until used. Thin, immature grains were not removed from the samples either before milling or before parboiling.

The grain types of the varieties (milled kernels) were: SR, extra long (7.7 mm.); CS, BS, HB, medium (5.6 mm.); and TN, short (5.1 mm.).

Parboiling

The method of parboiling (including reparboiling) was as described previously (14). All samples were shade-dried after parboiling to preclude any strain during drying (14).

Milling

Raw paddy (1 to 2 kg.) was shelled in a McGill sheller to obtain about 95% shelling in one pass, the residual paddy being separated by riddle 000 of a Carter dockage tester and reshelled. The brown rice (100 g. each) was milled in a McGill miller No. 1 with moderate manual pressure for different periods (30 sec. when time not stated). In one set of experiments the brown rice was first freed of all "brokens" in a rice-sizing device before being milled as before. The rice and the bran were sieved in a 18-mesh (B.S.S.) sieve to determine the percent loss in weight

[1] Paddy: rough rice; raw rice (or paddy) is rice (or paddy) that is not parboiled.

of brown rice on milling (degree of polish) as a measure of the reproducibility of the milling method. Parboiled paddy (125 g. each) was milled directly, to avoid the difficulty of sticky bran if milled after shelling (15) in the McGill miller No. 1 for 45 sec. (14). All brokens were recovered by sieving and aspirating and added to the rice.

Breakage (g. of grains less than three-fourths size per 100 g. brown or milled rice) was determined manually; an appropriate sizing plate was used. All paddy samples (raw and parboiled) contained 11 to 12.5% moisture (wet basis) at the time of milling.

Examination for Defects

Rice samples were examined 1) visually for size, color, and infestation; 2) by pressing gently between fingers for fragility; and 3) in transmitted light for cracks and chalkiness. Original paddy samples were examined similarly on about 200 grains after they were dehusked by hand. For the transmitted-light test, samples (3 to 6 g.) were taken in a Petri dish placed over a hole on a stool and examined through a hand lens with the help of a flashlight focused from below. Chalky portions showed up as opaque areas in the grain; cracks were revealed similarly, but showed up better when the flashlight was moved gently, or better still, when the grain was moved from shadow to light along its long axis. The following arbitrary classification of the defects was used: Immature: thin kernels, often green in color, with various portions (10 to 100%) chalky, and invariably very fragile. Chalky: mature grains with portions (half or more) chalky; moderately chalky, with quarter- to half-portions chalky; slightly chalky, with less than quarter-portion chalky. None of these chalky grains were fragile as tested here. Cracked: grains with clear, single or multiple (usually transverse) cracks, breaking easily along the line of fracture. Infested: kernels with colored pin-spots on surface that showed up well in transmitted light, often with a minute crevice extending from the point for some distance inward. Many of these kernels broke easily along the spot, but others did not.

Determination of cracked and immature grains, as defined, was reliable, particularly as it was corroborated by fragility. Determination of chalkiness, especially minute chalky areas, was less reliable, and the classification into three groups was rather arbitrary; hence these results were more useful in revealing trends than in absolute values. Cracks were examined only in brown rice, as milled rice often contained fresh cracks developed after milling. Often multiple defects were seen, but only the most serious one was considered for classification; e.g., a cracked, chalky grain was classified as "cracked." Cracks appeared to be distributed equally between chalky and nonchalky grains, but were not clearly detectable in truly immature kernels.

Hydration Studies

Field CS paddy was parboiled, damaged by drying directly to 13% moisture at 60°C., and spread in air for 1 day (14). Hydration characteristics of this and the original raw paddy were studied by methods described earlier (9). Samples at different stages of soaking were steamed simultaneously (10 min. at 0 p.s.i.g.), shade-dried, and milled for estimation of breakage as an indirect test of the optimum soaking stage for reparboiling.

The Boerner sample divider was used in all sampling.

TABLE I. BREAKAGE AND CHANGE IN DEFECTIVE GRAIN CONTENT ON PROGRESSIVE MILLING OF RICE

Milling[a] Time	Degree of Polish	Brokens in Rice	Whole Grains in Rice[b]							
			Cr	Im	In	Ch	MCh	SCh	S	Total
sec.	%	%	%	%	%	%	%	%	%	%
Shade CS										
Orig.	...	...	1.1	15.4	0.0	1.8	1.7	19.6	60.4	100.0
0	0.0	14.8	0.0	0.6	0.0	1.5	4.2	21.7	57.2	85.2
10 A	2.4	15.4	-	-	-	-	-	-	-	84.6
B	2.8	1.2	-	0.5	0.0	0.9	3.0	20.4	59.4	84.2
30 A	4.9	16.4	-	-	-	-	-	-	-	83.6
B	4.7	1.6	-	0.5	0.0	1.5	3.5	21.2	57.0	83.8
90 A	7.1	16.0	-	-	-	-	-	-	-	84.0
B	6.5	2.0	-	0.5	0.0	1.6	4.9	25.5	51.0	83.5
180 A	9.7	23.9	-	-	-	-	-	-	-	76.1
B	9.9	8.1	-	0.0	0.4	1.8	2.4	24.8	48.9	78.3
Field CS										
Orig.	...	...	30.8	1.4	1.5	0.9	1.4	10.5	53.5	100.0
0	0.0	32.1	1.9	0.2	0.5	1.9	0.8	10.5	52.1	67.9
10 A	2.9	32.9	-	-	-	-	-	-	-	67.1
B	3.1	0.5	-	0.2	1.5	1.5	1.9	7.2	55.2	67.5
30 B	5.1	0.9	-	-	-	-	-	-	-	67.3
90 B	6.3	0.9	-	-	-	-	-	-	-	67.3
180 B	9.5	12.8	-	-	-	-	-	-	-	59.2
Shade HB										
Orig.	...	...	0.8	6.6	0.9	9.4	12.7	48.5	21.1	100.0
0	0.0	11.3	0.0	1.3	0.5	5.5	10.8	51.2	19.4	88.7
30 B	5.3	0.6	-	-	-	-	-	-	-	88.2
Shade BS										
Orig.	...	...	1.0	4.6	0.0	5.0	9.4	20.2	59.8	100.0
0	0.0	5.7	0.0	0.0	0.5	4.7	8.7	24.4	56.0	94.3
30 B	4.4	0.7	-	-	-	-	-	-	-	93.6
Field SR										
Orig.	...	...	62.1	3.6	0.0	0.0	9.6	22.8	1.9	100.0
0	0.0	77.4	0.0	0.0	0.0	0.8	4.0	14.8	3.0	22.6
30 B	6.5	6.0	-	-	-	-	-	-	-	21.2
Field TN										
Orig.	...	...	75.6	7.0	0.0	0.5	5.6	9.0	2.3	100.0
0	0.0	80.1	3.2	1.5	-	-	-	-	-	19.9
30 B	2.6	10.3	-	-	-	-	-	-	-	17.9
Immature (Shade CS)										
Orig.	...	...	-	65.4	-	-	-	-	-	100.0
0	0.0	67.9	-	1.8	-	-	-	-	-	32.1
Parboiled CS										
30	-	0.5								
60	-	0.6								
90	-	0.6								
150	-	0.8								
Parboiled HB										
60	-	0.4								
150	-	0.5								

[a]Raw brown rice milled: A, as-is; B, after removal of brokens. "Orig." signifies manually dehusked grains; "0" time indicates shelling only. Parboiled paddy milled directly without shelling.

[b]Cr = cracked, Im = immature, In = infested, Ch = chalky, MCh = moderately chalky, SCh = slightly chalky, S = sound. Results expressed in percent by weight of the respective total rice (including brokens). In the case of B milling series (where brown rice brokens were removed piror to milling), values have been recalculated to the original basis so that all values can be directly compared.

RESULTS AND DISCUSSION

Breakage Pattern in Laboratory Milling of Raw Rice, and Its Relation to Kernel Defects

Progressive milling of rice with laboratory equipment showed, surprisingly, that most of the breakage occurred during the earliest stage of milling or even at the shelling state (Table I). Similarly, grains remaining unbroken after shelling gave little breakage when separated and milled. (A similar indication is found in the recent data of Desikachar et al. (13,15).) It appeared as if some of the grains were certain to break, and broke quickly (compare also ref. 1); others, for the most part, did not break, or broke partly only after very prolonged stress (180 sec., at which stage the rice was extremely hot). To elucidate these results, the kernels were examined for defects in transmitted light.

It was found that all the late-harvested, field-dried lots (Field CS, Field SR, Field TN) contained a large number of cracked kernels which were negligible in the early-harvested, shade-dried lots (Table I). These differences were also reflected in their total breakage. The latter lots (Shade CS, Shade HB, Shade BS), on the other hand, contained an appreciable amount of immature kernels, and the breakage, small as it was, appeared to be largely related to these kernels. This conclusion was confirmed when a sample of immature paddy, separated from the Shade CS lot by winnowing, had markedly increased breakage over the original Shade CS lot. This sample contained about two-thirds immature kernels; brown rice yield, 65.5% in place of 76% for the original lot.

That the breakage was mostly related to these two factors was shown by two facts: 1) that the cracked and immature whole kernels practically disappeared after shelling in all samples, and 2) that their total content was closely related to the total loss in head yield in each. Some of the infested kernels also appeared to be involved in the breakage. It was not clear from the results whether some of the chalky grains also preferentially broke, partly owing to the difficulty of accurate analysis and the consequent variability of results; but on the whole it appeared not; they were not fragile when tested between fingers. Analysis of broken pieces was undertaken but gave no additional information, for chalky pieces could originate from chalky, immature, or cracked kernels; similarly, sound pieces could originate from any kernel other than 100% chalky.

Effect of Parboiling on Breakage and on Defective Grains

In spite of differing and sometimes large initial breakage, all the lots gave very low or negligible brokens after parboiling (Table II). As further evidence, a portion of the Field CS lot was subjected to both overdrying and wetting to induce extensive cracking (16) (as was also reflected in very severe breakage), and then parboiled. The dramatic restoration of milling quality (Table II) left no doubt that any type or extent of cracking was healed by parboiling. Similarly, the immature paddy (Shade CS) had very low breakage when parboiled.

Examination in transmitted light not only confirmed the absence of cracks in the parboiled lots but also showed the absence of chalkiness in any of the kernels. Even the tiny immature kernels, observed especially in the sample of immature paddy, appeared flinty and translucent and remained unbroken after milling.

TABLE II. MILLING BREAKAGE OF PADDY HANDLED IN DIFFERENT WAYS AND EFFECT OF PARBOILING

Paddy	Treatment	Brokens in Rice on Milling	
		As-Is %	After Parboiling %
Field CS	Nil	32.7	0.7
	Dried[a]	100.0	0.9
	Wetted[b]	71.0	0.8
Field SR	Nil	78.8	3.6
Field TN	Nil	82.1	0.0
Shade CS	Nil	16.4	0.5
Shade HB	Nil	11.7	0.5
Immature (Shade CS)	Nil	67.9[c]	3.3
Parboiled CS	Nil	0.6	-
	Overdried[d]	99.0	0.4[e]
	Wetted[b]	10.5	0.7[e]

[a]Paddy dried in 105°C. oven for 6 hr., then exposed to atmosphere in a tray for 24 hr.

[b]Paddy put in water at room temp. (26° to 28°C.) for 2 hr., then shade-dried.

[c]Refers to breakage after shelling. Further milling could not be done as the immature kernels had broken into minute fragments which passed out through the mill screen.

[d]After parboiling, paddy dried with 60°C. air directly to about 11% moisture, then put out in a tray in the shade for 20 hr.

[e]In these cases, parboiling signifies reparboiling (soaking plus steaming).

These results provided a clear explanation·for the well-known improvement in milling quality of paddy after parboiling.·It is clear that kernel defects such as cracks, chalkiness, and immaturity are completely eliminated on parboiling, apparently owing to realignment and cementing of the grain constituents after cooking of the starch, and that improvement in milling quality is evidently related to this phenomenon. Ideally, breakage therefore should always be negligible after parboiling, as was observed here. The divergence in this respect in earlier literature (compare ref. 9,10,12,13) was probably caused by failure to realize the effect of drying conditions of parboiled paddy on its milling quality. While previous defects are no doubt healed by the process, fresh cracks can arise from improper drying and thus partly (or even completely) nullify the advantage (10,14), which may have been the reason for some breakage in earlier studies. On the other hand, whenever drying has been in shade or under appropriate conditions, milling breakage after parboiling has been very low or negligible, irrespective of its incidence in the original raw paddy (9,10,13,14).

Progressive milling of parboiled rice showed absolutely no increase in breakage with longer milling time, differing from that of raw rice in which a very slight increase generally occurred (Table I). This result might imply that parboiled rice was harder or more resilient compared to raw rice, and this probably played an additional but minor part in its improved milling quality. But this view is as yet unconfirmed, since the slight breakage in raw kernels after prolonged stress may have been due to latent infinitesimal defects (chalky kernels, for instance) rather than to poorer mechanical strength of raw rice in general.

Reparboiling of Damaged Parboiled Paddy

Parboiling not only restored the milling quality of damaged raw paddy but also

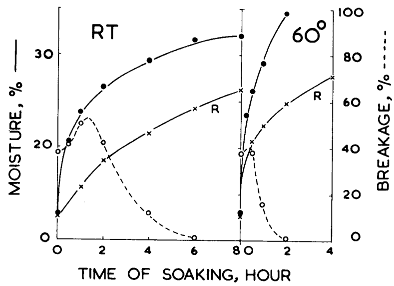

Fig. 1. Moisture uptake by drying-damaged parboiled CS paddy on soaking in water (at RT, room temperature, 26° to 29°C., and at 60°C.) and milling breakage after steaming and drying. Original Field CS raw paddy soaked for comparison (R).

of parboiled paddy with induced cracks (Table II). Evidently the cracks were healed, as before, during the fresh cooking. Reparboiling could therefore perhaps be useful in salvaging damaged parboiled paddy. The reparboiled samples were a shade yellower than the original parboiled lots but otherwise were indistinguishable.

The hydration pattern of parboiled paddy was investigated, since after the usual soaking (for reparboiling) the grains had visibly overimbibed. It was found that parboiled paddy absorbed water much faster than raw paddy (Fig. 1), possibly because previous gelatinization or slight opening of the hulls, or both, facilitated hydration. About 6 hr. at room temperature and 2 hr. at 60°C. was enough for the soaking compared to approximately 60 and 6 hr., respectively, for raw paddy (9). Thus reparboiling appeared to be economically feasible.

GENERAL DISCUSSION

The importance of kernel defects in rice milling and the improvement in milling quality after parboiling have long been recognized qualitatively. The present results furnish quantitative information on these phenomena and also explain their precise implications.

It is clear that cracked and immature rice grains were very fragile and almost disappeared on milling, that what breakage occurred under the conditions of these experiments occurred early and quickly, and that most of the total breakage could be accounted for by the reduction in cracked and immature whole kernels – all of which together suggests that it is principally the defective grains that ultimately fail in rice milling. This implies that the ultimate cause of breakage in rice milling resides more in the rice kernel than in the milling methods and equipment, and that improvements should therefore be directly primarily to harvesting, drying, and premilling handling (1–4) to preserve the grain quality. Yet there is evidence (8) that the actual (but probably not the potential) breakage, particularly in commercial milling, is influenced by the milling conditions. Other factors as discussed earlier may also play some part. There is, therefore, need for further comprehensive studies on the interrelations among milling conditions, type of equipment, moisture content, and kernel quality to evaluate the various factors in their true perspective.

It has been established that cracks, chalkiness, and incomplete grain filling are completely healed during the parboiling process. Milling quality of paddy after parboiling is, therefore, not just improved but determined *de novo*, irrespective of the previous history or condition of the lot, and determined solely by its own drying condition. Consequently, harvesting, drying, and other handling by preparboiling should be determined in areas where parboiled rice is consumed, by considerations other than that of preserving the best milling quality. For the same reason, parboiling is an excellent tool for salvaging any paddy, raw or parboiled, whose milling quality has been inadvertently damaged by sun, rain, or faulty drying; as well as paddy containing a high proportion of immature kernels which otherwise would be extremely fragile and would break easily into minute fragments when milled.

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