Conditions of Drying Parboiled Paddy for Optimum Milling Quality[1]

KSHIROD R. BHATTACHARYA and **Y. M. INDUDHARA SWAMY,** Central Food Technological Research Institute, Mysore, India

ABSTRACT

Parboiled paddy dried in the shade had excellent milling quality, but rapid drying with hot air (40°–80°C.) or in the sun gave high breakage. The damage started as the moisure content reached 15% and increased sharply with further drying. Milling at different time intervals after drying demonstrated further that damage to the paddy occurred gradually only subsequent to its removal from the dryer. From this it was found that keeping the paddy hot after drying (conditioning) for about 2 hr. prevented the milling breakage. Drying in two stages with a tempering (2 hr. if hot, 8 hr. if at room temperature) just before attainment of the critical moisture content (at 15.5–16.5%) also preserved milling quality. Tempering at higher moisture contents was less beneficial, and multiple tempering gave no additional benefit. Drying in two passes with a tempering in the moisture range of 15 to 19%, followed by hot-conditioning after the final drying, was convenient in practice and satisfactory; a drying temperature up to 80°C. could be used. After parboiled paddy was dried in this way, milling breakage would not exceed 1–2%.

The remarkable influence of drying conditions on the milling quality of parboiled paddy (rough rice) was demonstrated in an earlier communication (1). Slow drying in the shade enabled excellent head yield to be obtained from paddy parboiled under any conditions; but on rapid drying with hot air or in the sun, only paddy parboiled with severe heat-treatment retained satisfactory milling quality. Severe processing conditions. however, have other disadvantages (2,3); hence, a detailed study of the influence of drying conditions on the milling quality of parboiled paddy was undertaken. Work on this aspect has been limited (4–6).

MATERIALS AND METHODS

The rice used was a common fine-grained variety, Coimbatore Sanna, procured through commercial channels.

Parboiling

Soaking was carried out simply by putting paddy (1–4 kg.) in hot water (90°–95°C.) in a metal pail, covering with jute sacks, and leaving overnight. This procedure enabled sufficiently rapid hydration without requiring any particular care; yet, as the temperature dropped quickly below the gelatinization point, other effects of high-temperature soaking (2,3) were avoided. After the immature grains were skimmed off and the paddy was drained and washed, it was steamed for 10 min. at atmospheric pressure (1). Parboiling thus was done, on the whole, under mild conditions, so that the drying conditions could be tested on a more susceptible grain.

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Drying

Main experiments were carried out in a large overdraught cabinet dryer (capacity 48 trays of size 32 by 16 in.). The paddy was taken on wire-mesh trays (tray load of 0.5 kg./sq. ft., only one or two trays being used at a time) and stirred manually at intervals of 5 to 10 min. (Very frequent stirring was subsequently found to be unnecessary.) Moisture was determined at intervals and samples were withdrawn at desired stages after thorough mixing. The drying curves are shown in Fig. 1. Certain lots were dried in the sun and

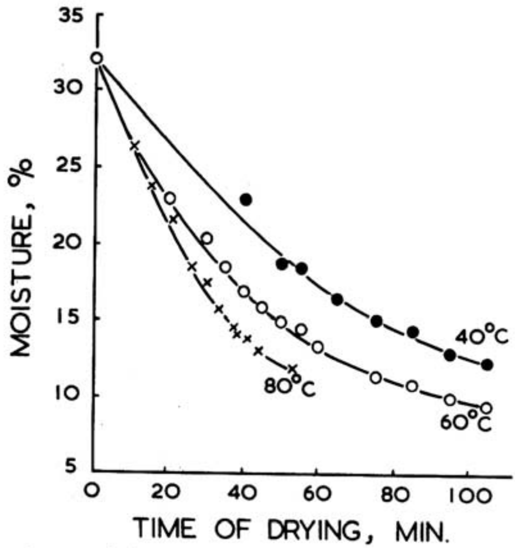

Fig. 1. Drying characteristics of parboiled paddy (CS) at different temperatures.

control samples in the shade. Unless otherwise mentioned, drying was followed by "holding" of the samples until milling (see below).

Moisture

Moisture was determined in the paddy (ground in a hand mill), within 2 min. of its removal from the dryer, with a Marconi moisture meter (Type TF 933A) previously calibrated under identical conditions of operation against the official AACC vacuum-oven method (7). All moisture data are expressed on wet basis.

Holding, Conditioning, and Tempering

These terms describe essentially the same process of hermetic storage of paddy (in stoppered glass bottles filled to the neck) for achieving moisture equilibration. "Holding" refers to storage at room temperature (RT, 26°–32°C.) for 18–34 hr. before milling. (The grains were spread in a tray for 2–3 min. to cool before they were put into the bottles; slow cooling in the bottle was not feasible because condensate appeared on the walls.) "Conditioning" refers to storage at elevated temperatures after drying; this was always followed by cooling and holding as above. "Tempering" refers to an intermediate storage (either hot or at room temperature) between two passes of drying. For conditioning or hot-tempering, paddy from the dryer was put into heated bottles and stored in an oven maintained at the desired temperature.

Milling

Samples (125 g. paddy each) were milled in a McGill miller (No. 1), pressure being applied manually for 60 sec. Broken grains passing through the mill screen into the bran were recovered by winnowing and sieving. Breakage was determined by hand picking (1), all results being expressed as "milling breakage" (g. broken grains in 100 g. milled rice). No other yield data were determined.

A few experiments carried out initially by milling the rice after shelling in a McGill sheller yielded the same trend of results. Direct milling was therefore adopted for its greater convenience.

Replication and Precision

The milling procedure adopted gave reproducible results of breakage, as is evident from the table below. Milling and breakage analyses were therefore carried out on single samples. Drying experiments were carried out in several replicates each; trends of the results were always reproducible, but the actual values varied.

Sample No.	*Replicate Results of Breakage* %
1	0.5, 0.9, 0.8, 0.6
2	17.9, 19.2
3	45.6, 47.3
4	98.5, 99.0

RESULTS AND DISCUSSION

Onset of Damage to the Grain

Slow drying of wet parboiled paddy in the shade gave excellent milling results: 0.4–1% breakage; the figure went up to 3% if the paddy was spread thinly on a very dry day. Rapid drying with hot air, however, led to high breakages (Fig. 2) (1,4,6). Drying with hot air to different stages, followed by spreading in the shade to complete the drying and to equalize moisture (Fig. 2, A), revealed that the milling quality of the grain was not affected until a moisture content of about 15% was reached (4,6); damage started at that point and increased sharply with further drying. Trend of the results was the same under all conditions, so that drying at lower temperatures (40°C., sun) or with air of gradually reduced temperature (80° to 40°C.) or even with ambient air toward the end (Fig. 2, inset) could only reduce but not prevent milling breakage. Holding the paddy after drying (rather than spreading out) reduced the breakage to some extent but did not

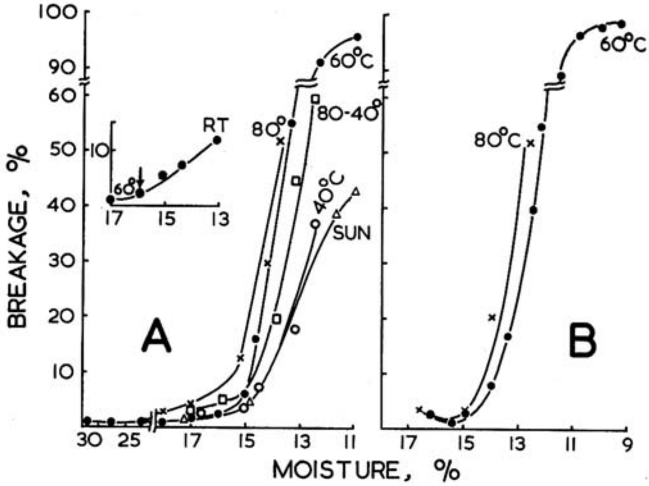

Fig. 2. Milling breakage of parboiled paddy dried with hot air to different moisture contents. Batch shown in inset dried to 15.9% moisture (arrow) with air at 60°C., then with ambient air (30°C.). A, samples from dryer spread in the shade for 20–40 hr. before milling (final moisture, 11–12.5%). B, samples from dryer merely "held" before milling.

alter the pattern of the results (Fig. 2, B). (The slightly higher breakage in the earlier stages in these lots is apparently the result of milling high-moisture paddy rather than of any damage; it disappeared after further shade-drying.) These results are in agreement with earlier observations (8,9) that development of cracks in rice on wetting or rapid drying occurs only below 15% moisture.

Milling parboiled paddy at different time intervals after drying revealed further that damage to the grain occurred only subsequent to its removal from the dryer (Table I, 12.4 and 14.0% moisture). It was observed that cracks

TABLE I

Effect of Milling Parboiled Paddy at Different Time Intervals after Drying at 60°C.

Time of Holding after Drying	Milling Breakage of Paddy: Dried to 15.9% Moisture	Dried to 14.0% Moisture	Dried to 12.4% Moisture	Time of Holding after Drying	Milling Breakage of Paddy: Dried to 15.9% Moisture	Dried to 14.0% Moisture	Dried to 12.4% Moisture
hr.	%	%	%	*hr.*	%	%	%
0.0[a]	25.8	14.1 (+)[b]	4.8 (++++)	2	3.5	11.3	40.7 (+++)
0.1	15.4	4.9 (+)	3.3 (++++)	3	3.0	13.1	47.3 (++)
0.5	7.4	5.2 (+)	9.9 (+++)	5	....	14.2	52.0 (++)
1	5.0	7.0	24.1 (+++)	24	2.8	15.0	54.1 (+)

[a] Sample milled hot immediately after drying.
[b] Number of plus signs indicates the relative number of cracks that developed in rice after milling.

started to appear gradually in the early-milled (0 and 0.1 hr.) rice grains about 15 min. after milling and continued for about 2 hr. Evidently cracks developed also in the unmilled grains in a similar way, which explains why milling breakage was minimal at the beginning and increased with time. Fewer cracks were present in samples milled subsequently, because the cracked grains would already have broken during milling. Craufurd (9) has demonstrated also that cracks develop in paddy only after drying has ceased. These results confirmed the paradoxical observation of Sluyters (6) that milling breakage of sun-dried parboiled paddy increased with storage.

Curiously, the high-moisture sample (15.9%) gave high breakage on early milling, which decreased on milling after holding. This was presumably because of the shear set up during milling between the hard surface (dry) and plastic core (excessively wet) resulting from the moisture gradient set up by drying. As the gradient was resolved by holding, the breakage also declined.

Temperature of the grain *per se* at the time of milling did not appear to affect its milling quality.

Effect of Conditioning

Since cracks in the dried grain developed not during drying but subsequently, it appeared that keeping the paddy hot for some time after drying

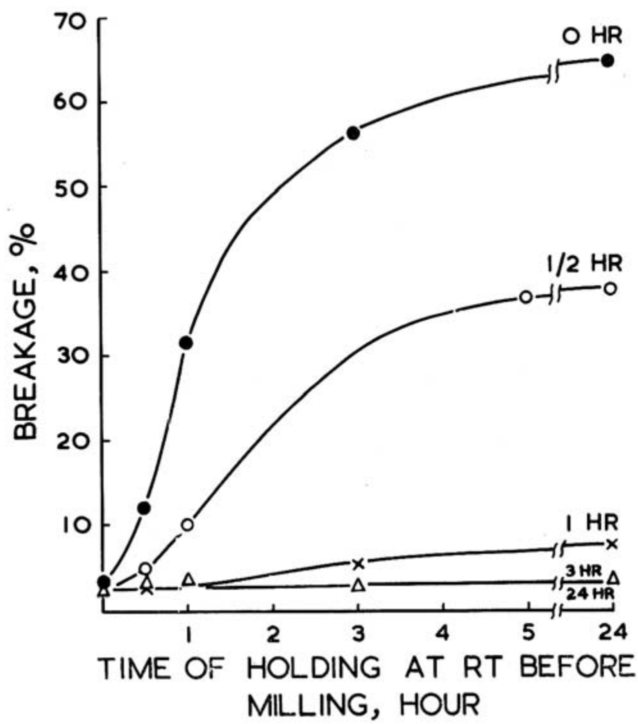

Fig. 3. Effect of conditioning (50°C.) for different periods on milling breakage of parboiled paddy dried at 60°C. to 12.4% moisture. Paddy milled at different time intervals of holding at room temperature (abscissa) after conditioning.

(conditioning) might protect it from damage. This was found true, conditioning for about 2 hr. being adequate (Fig. 3). No cracks developed in rice milled after conditioning. For best results, conditioning had to be done at a temperature close to that of the drying, although underdried paddy could be protected at lower temperatures (Table II).

As the paddy was always cooled rapidly after conditioning, it is clear that cooling *per se* was not responsible for development of cracks in the grain. Apparently, cooling is harmful if the grain has a high moisture gradient, but not otherwise.

With drying at high temperatures (60°, 80°C.), suitable conditioning could always prevent milling breakage (Table II). But paradoxically, at

TABLE II

EFFECT OF CONDITIONING AT DIFFERENT TEMPERATURES ON MILLING BREAKAGE OF DRIED PARBOILED PADDY

Drying Air Temperature	Moisture Content to Which Dried	Breakage on Milling after Conditioning					
		At RT	At 38°C.	At 45°C.	At 50°C.	At 60°C.	At 75°C.
°C.	%	%	%	%	%	%	%
80	14.0	29.0	....	....	0.9	....	1.1
	12.3	71.8	....	....	6.4	2.3	0.9
	11.1	89.4	....	....	59.9	17.0	1.5
60	13.5	24.2	....	....	0.6	0.8	....
	12.4	59.5	25.6	....	3.5	1.0	....
40	12.6	15.4	5.0	2.8	1.5	....	....
80 to 40	12.6[a]	31.0	15.1	7.2	6.4	2.9	....
	12.5[b]	49.0	20.3	11.3	9.7	5.5	....
60 to RT	12.4[c]	7.2	6.2	....	2.6	....	....
	12.5[d]	15.6	....	11.1	8.3	....	....
Sun[e]	12.4	13.6	8.0	....	4.4	1.8	....

[a] Drying temperature progressively reduced from 80° to 40°C.; 40° reached at 17% moisture.
[b] Same as above, but 40° reached at 14% moisture.
[c] Temperature reduced progressively from 60° to 33°C.
[d] Dried at 60°C. to 14.4% moisture, then with ambient air (30°C.).
[e] Temperature 40°–43°C.

lower drying temperatures (40°, 80–40°, sun), although the tendency to damage was less, complete protection could not be obtained by conditioning. Drying at 80°–40°C. in particular gave rather poor results even when the air temperature was reduced to 40°C. before the critical moisture content of 15% was reached (so that the grain was not subjected to any cooling at this critical stage). These results, checked repeatedly, remain unexplained. Another unexplained observation was the progressive decrease in milling breakage with increasing temperature of conditioning even beyond the drying temperature (40°, 80°–40°, 60°–RT, sun). Apparently hot-conditioning *per se* has some beneficial effect apart from the indirect effect of arresting cooling.

Effect of Tempering

When the moisture gradient of the paddy was resolved just before the critical stage (around 16% moisture) by tempering, subsequent drying did not lead to increased milling breakage up to a moisture content of about

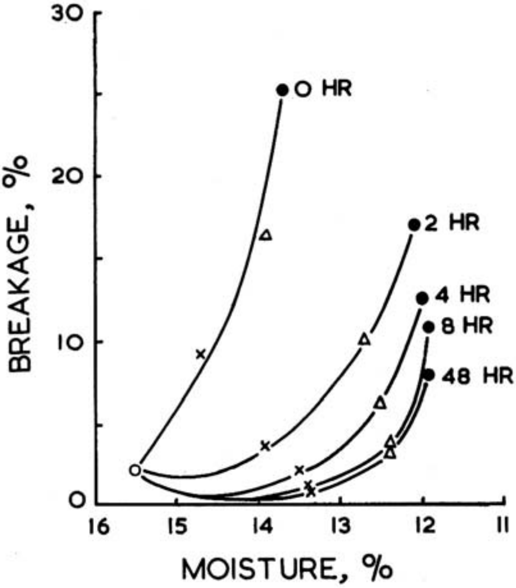

Fig. 4. Effect of drying with tempering on milling breakage of parboiled paddy. Drying temperature, 60°C.; initial drying to 15.5% moisture (○). Tempered at room temperature (27°–30°C.) for different periods and dried for 5 (×), 10 (Δ), and 15 (●) min. each.

12.5% (Fig. 4). Tempering for about 8 hr. at room temperature (see Fig. 4) or for 2 hr. at 50°–60°C. was optimal. Tempering had the added benefit of increasing the drying rate (Fig. 4) so that the in-dryer drying time could be reduced.

Tempering at earlier stages (higher-moisture paddy) was less beneficial than at just before the critical stage; but it could still be satisfactory if the paddy was less fully dried finally (14% moisture) (Table III). Tempering at moisture contents below the critical stage (13.8%) was beneficial if it was done at elevated temperatures but not at room temperature, because cooling at these stages would induce cracks. (Above 15% moisture, of course, tempering at room temperature was equally satisfactory—see Fig. 4.) For normal requirements of drying (final moisture, 12–14%), multiple tempering was no more beneficial than a single tempering at the critical stage. Hot-conditioning following drying in two passes was, as expected, of additional benefit.

The general applicability of these conditions was attested by their successful application to two other varieties of paddy.[2] Even partially parboiled rice (with "white belly"), well known for its susceptibility to breakage during milling (1,10), could be dried without damage with a correct combination of

[2]BS and RC, not shown. The slight difference in the milling quality of BS and RC parboiled rice observed earlier (1) appears in retrospect to be an artifact. Perhaps the ambient humidity was low when the BS batch was dried, causing a slightly increased breakage.

TABLE III

EFFECT OF DIFFERENT TEMPERING DURING DRYING OF PARBOILED PADDY ON ITS MILLING BREAKAGE

DRYING-AIR TEMPERATURE	MOISTURE CONTENT AT WHICH TEMPERED[a]	MOISTURE CONTENT TO WHICH FINALLY DRIED	BREAKAGE AFTER CONDITIONING		
			At RT	At 50°C.	At 70°C.
°C.	%	%	%	%	%
60	....	12.5	50.1	3.5	....
	24.0	12.5	40.2	....	....
	20.8	12.4	31.2	3.0	....
	18.9	12.4	5.8	1.7	....
	17.0	13.9	1.1	....	....
		12.5	4.0	....	....
	16.0	14.0	0.7	0.2	....
		12.5	1.3	0.5	....
	13.8	12.5	0.2	....	....
	13.8[b]	12.6	16.2	....	....
	18.9, 16.0	12.4	1.2	....	....
	20.8, 18.3, 15.5	12.5	1.3	....	....
60[c]	....	12.4	92.0	43.9	....
	15.9	12.5	20.8	1.1	....
80	....	12.6	74.4	8.3	1.5
	21.0	12.6	44.0 (12.0)[d]	....	....
	17.5	14.1	2.2 (0.7)	....	....
		12.6	33.4 (11.0)	1.9	1.0
	16.4	14.2	1.0	....	....
		12.6	6.0 (0.7)	2.3	0.9
	18.2, 15.9	12.6	.... (2.3)	....	....
	21.0, 18.4, 16.0	12.5	.... (4.5)	....	....

[a] Tempered at 50°–60°C. for 2–3 hr. unless otherwise mentioned.

[b] Tempered at room temp. (27°–30°C.) for 20 hr.

[c] Experiment with undersoaked parboiled paddy (soaked for 40 hr. at room temperature; rice contained "white belly").

[d] Figures in parentheses refer to results of tempering at 80°C. instead of at 50°–60°C.

tempering and conditioning (Table III). This result is important inasmuch as it enables utilization of partially parboiled rice which combines the nutritional benefit of parboiling with the cooking quality of raw rice (2,3,10).

CONCLUSIONS

Parboiling is commonly considered to improve the milling quality of paddy. The present results show that this is true only if the paddy is dried under carefully controlled conditions.

Damage, potentially severe, occurs when parboiled paddy is dried rapidly with hot air as the moisture content drops below 15%. The damage manifests itself only when the grain cools, and seems to be related to its high moisture gradient. The damage can, therefore, be prevented by hot-conditioning after drying, which prevents cooling; or by drying in two passes with an intermediate tempering just before the critical moisture stage, which minimizes the moisture gradient. In practice, complete avoidance of cooling after drying would be rather difficult to achieve; so would be tempering at a predetermined moisture content of 15.5–16.5%. The most convenient practice would be to dry in two passes with a tempering in the moisture range of

15–19%, followed by conditioning after final drying; the latter is accomplished merely by heaping after drying. When parboiled paddy is dried in this way, even when it is produced under very mild conditions of processing, breakage in milling need not exceed 1–2%, including brokens lost in bran.

Working at relatively lower temperatures does not appear to offer any advantage; drying at 60°–80°C. is equally satisfactory and faster. Similarly, drying with multiple tempering is of no additional benefit to the milling quality, although it may be of value for increasing the drying rate.

These suggested conditions would hold mainly for drying lightly parboiled paddy and may not all be required for drying heavily parboiled paddy, which, as mentioned earlier, can be dried satisfactorily under more simple conditions.

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