Response of Starch of Different Wheat Classes to Ball Milling[1]

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ABSTRACT

Starches isolated from different wheat classes (durum, hard red spring, hard red winter, soft red winter, and white wheats) with minimum damage were ball milled for 0–24 hr. The response of starch to ball milling for the different wheat classes was investigated to see whether the differences in the sensitivity of starch granules to mechanical action among the wheat classes were also responsible for the different degrees of starch damage with respect to wheat hardness. Upon ball milling, the degree of starch damage showed the following trend with respect to wheat type: durum wheats showed a higher degree of damage than hard wheats, which had more damage than soft wheats. This indicates that the starch in hard wheat is susceptible to the physical action of milling and that the strong starch-protein bonds might contribute to a high degree of starch damage after milling. The degree of swelling and the water-solubility index followed the same trends as the degree of starch damage based on wheat type.

When starch and starch-containing materials are ground, some starch granules are damaged by the mechanical action of the milling process (Lelievre 1974). The damaged fraction may be distinguished microscopically by staining with dyes or by loss of birefringence (Evers and Stevens 1985). The damaged starch shows a smaller endotherm peak area of differential scanning calorimetry than unmodified starch (Stevens and Elton 1971). Damaged starch swells extensively in cold water, and the swelling is limited to the damaged portion of the starch granules (Sandstedt 1961. Therefore, the damaged starch plays a significant role in water absorption of flour (Tara et al 1972). Damaged starch is important in breadmaking because of its high water-absorption capacity and high susceptibility to enzymes. (Evers and Stevens 1985).

The degree of starch damage is affected by wheat type, tempering moisture, feed rate, roll-surface condition, and roll speed and differential of the flour-milling process. Starch damage is directly related to wheat hardness: the harder the wheat, the higher the level of damaged starch after milling (Bass 1988). Meredith (1969) found that vitreous wheat produces flour with a higher level of starch damage than nonvitreous wheat.

The level of starch damage has been related only to the bonds between starch and protein of wheat (Hoseney and Seib 1973, Simmonds 1974). In soft wheat, the starch-protein bonds are weak; thus, when sufficient force is applied across the cell during milling, the starch-protein bonds break before the starch granules do. However, in hard and durum wheats, the starch granules break more readily than the starch-protein bonds since the bonds are stronger in these wheats. As a result, hard wheat shows high starch damage after milling.

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This study was done to determine whether the isolated starch granules of various wheat classes respond differently to the mechanical action and, if so, to investigate whether the degree of starch damage among the wheat types is due to these differences as well as to the strength of the starch and protein bonds, as described above.

MATERIALS AND METHODS

Descriptions of starch samples and procedures for starch isolation and determination of degree of starch damage are given in the companion article (Mok and Dick 1991). Ball-milling procedures were also the same, except that 300 g of starch was ball milled for periods of 2–24 hr at room temperature without adjusting the relative humidity.

Degree of Swelling

Degrees of swelling of ball-milled starch samples were measured by the method of Wootton and Chaudhry (1980) with slight modification. Each starch sample (0.25 g of dry matter) was dispersed into 25 ml of water using a Sorvall Omni-Mixer (Sorvall Inc., Newport, CT) at medium speed (position 6) for 1 min. The suspension was centrifuged at $2,000 \times g$ for 10 min. Duplicate aliquots (0.25 ml) were pipetted into 10-ml volumetric flasks into which iodine solution (4% KI, 1% I_2; 0.1 ml) was then added. The mixture was diluted to 10 ml with distilled water. Absorbance (A_1) at 600 nm was measured against a reagent blank. Another suspension of damaged starch (0.25 g of dry matter ball milled for 24 hr) in distilled water (24 ml) was prepared as described above to prepare a completely swelled reference. Potassium hydroxide solution (10*M*, 1 ml) was added to the suspension, which was mixed gently on a Sorvall Omni-Mixer at low speed for 5 min. The alkaline suspension was then centrifuged. Duplicate aliquots (0.25 ml) were mixed with HCl (0.5 *M*, 0.25 ml) and iodine solution (0.1 ml) in 10-ml volumetric flasks and were diluted to 10 ml with distilled water. Absorbance [(A_2)] was measured as described above. Degree of swelling was calculated as [A_1/A_2].

Water-Absorption Index and Water-Solubility Index

The water-absorption index (WAI) and water-solubility index (WSI) were measured by the methods described by Anderson et al (1969) with modification . Each ball-milled starch sample (0.5 g of dry matter) was suspended in 10 ml of water in a tared 15-ml centrifuge tube. The tube was capped with a rubber stopper, agitated on a tube shaker at room temperature for 30 min, and centrifuged at 3,000 $\times g$ for 10 min. The supernatant was poured carefully into a tared evaporating dish. The WAI was calculated from the weight of the remaining gel and was expressed as grams of water per gram of solid. The WSI, expressed as grams of solid per gram of original (0.5 g) solid, was calculated from the weight of dry solids recovered by evaporating the supernatant overnight at 110°C.

RESULTS AND DISCUSSION

Degree of Starch Damage

Figure 1 shows the degree of damage to each ball-milled starch sample from the different wheat classes. Results of Duncan's multiple range test (Ott 1988) for the degree of starch damage indicated that durum wheat starch showed the highest level of damage, followed by hard wheat and soft wheat (Table I). The harder the wheat is, the more sensitive the starch from that wheat is to physical damage. Durum wheat is generally recognized as the hardest, followed by hard wheats and soft wheats. Kulp et al (1980) showed that the degree of starch damage caused by milling varies between wheat classes; hard wheat shows greater starch damage than soft wheat.

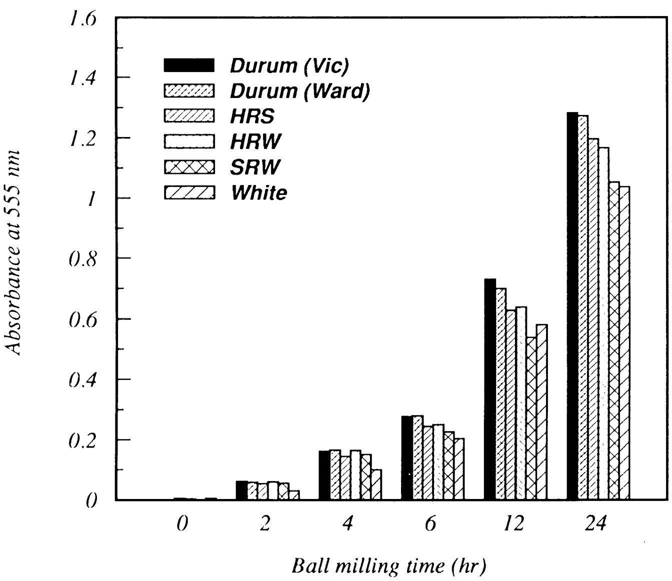

Fig. 1. Degree of damage of ball-milled starches of different wheat classes. HRS = hard red spring, HRW = hard red winter, SRW = soft red winter.

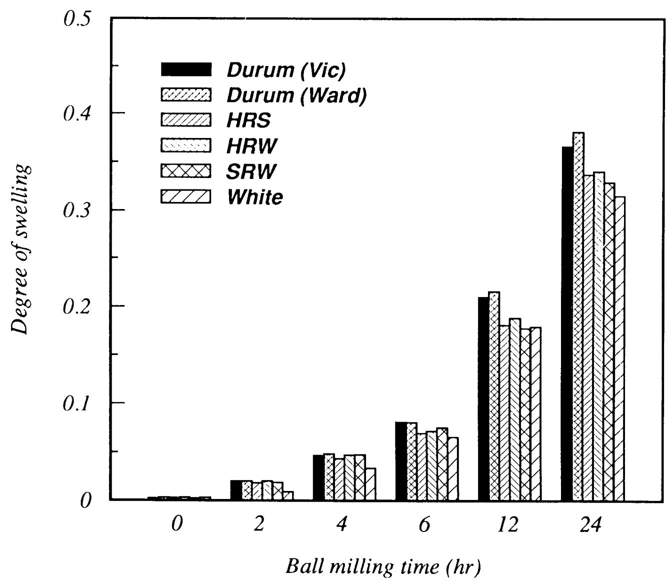

Fig. 2. Degree of swelling of ball-milled starches of different wheat classes. HRS = hard red spring, HRW = hard red winter, SRW = soft red winter.

TABLE I
Duncan's Multiple Range Test for Starch Damage of Ball-Milled Wheat Starch

Factor	Mean Starch Damage[a] (absorbance at 555 nm)
Wheat type[b]	
Durum	0.2939 a
Hard	0.2657 b
Soft	0.2332 c
Wheat sample[c]	
Vic durum	0.2953 a
Ward durum	0.2924 a
Hard red winter	0.2701 ab
Hard red spring	0.2612 bc
Soft red winter	0.2397 cd
White	0.2267 d
Ball-milling time[d]	
24.0	1.1672 a
12.0	0.6353 b
6.0	0.2467 c
4.0	0.1399 d
3.0	0.0982 e
2.0	0.0530 f
1.0	0.0235 fg
0.5	0.0123 g
0	0.0022 g

[a] Means of each effect with same letter are not significantly different ($P = 0.05$).
[b] n = 36.
[c] n = 18.
[d] n = 12.

TABLE II
Duncan's Multiple Range Test for Degree of Swelling of Ball-Milled Wheat Starch

Factor	Mean Degree of Swelling[a]
Wheat type[b]	
Durum	0.0875 a
Hard	0.0787 b
Soft	0.0741 b
Wheat sample[c]	
Ward durum	0.0886 a
Vic durum	0.0863 ab
Hard red winter	0.0800 ab
Soft red winter	0.0776 bc
Hard red spring	0.0774 bc
White	0.0705 c
Ball-milling time[d] (hr)	
24.0	0.3449 a
12.0	0.1922 b
6.0	0.0739 c
4.0	0.0442 d
3.0	0.0302 e
2.0	0.0177 f
1.0	0.0094 fg
0.5	0.0055 g
0	0.0026 g

[a] Means of each effect with same letter are not significantly different ($P = 0.05$).
[b] n = 18.
[c] n = 9.
[d] n = 6.

Wheat hardness and starch damage during milling have been attributed only to the starch-protein bonds of wheat (Hoseney and Seib 1973, Simmonds 1974). The results of the present study, however, indicate that the sensitivity of the starch granules to mechanical action differs with respect to wheat class. The starch granules of hard wheats such as durum, hard red spring, or hard red winter were more susceptible to mechanical action than those of soft wheats such as soft red winter or white wheat. The high susceptibility of hard wheat starch to mechanical damage might also contribute to the high degree of starch damage of hard wheat flour, in addition to the presence of strong starch-protein bonds as indicated by Hoseney and Seib (1973).

There were no significant differences in the degree of starch damage between wheat samples of the same type; i.e., between Vic and Ward durum wheats, between hard red spring and hard red winter wheats, or between soft red winter and white wheats (Table I).

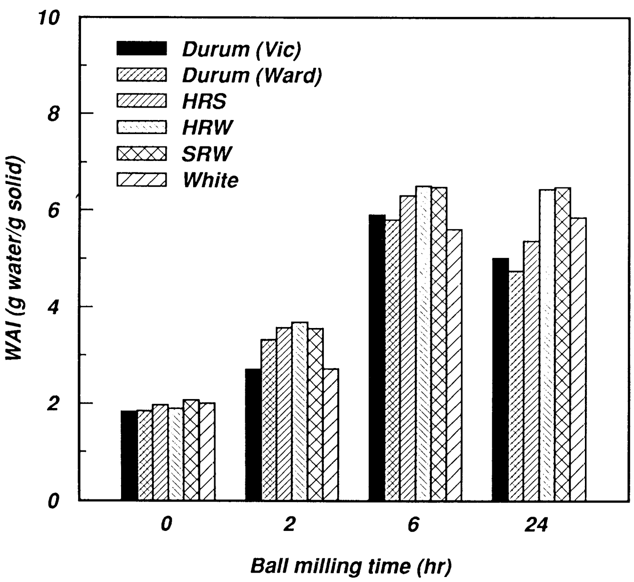

Fig. 3. Water-absorption index (WAI) of ball-milled starches of different wheat classes. HRS = hard red spring, HRW = hard red winter, SRW = soft red winter.

TABLE III
Duncan's Multiple Range Test for Water-Absorption Index of Ball-Milled Wheat Starch

Factor	Mean Water-Absorption Index[a] (g of water/g of solid)
Wheat type[b]	
Hard durum	4.4694 a
Soft	4.3481 a
Durum	3.8996 b
Wheat sample[c]	
Soft red winter	4.6472 a
Hard red winter	4.6326 a
Hard red spring	4.3061 ab
White	4.0490 b
Ward durum	3.9311 b
Vic durum	3.8681 b
Ball-milling time[d]	
6	6.1043 a
24	5.6523 b
2	3.2596 c
0	1.9398 d

[a] Means of each effect with same letter are not significantly different ($P = 0.05$).
[b] n = 16.
[c] n = 8.
[d] n = 12.

Degree of Swelling

Sandstedt (1961) showed that damaged starch swells extensively in cold water and that the swelling is limited to the damaged portion of the starch granule. Williams (1969) observed the loss of birefringence of starch resulting from ball milling, which indicates the loss of organized structure.

In our study, ball-milled durum wheat starch showed a higher degree of swelling than ball-milled starch of the other wheat types (Fig. 2, Table II). Durum wheats showed significantly higher degrees of swelling than either hard or soft wheats. There was no significant difference in the degree of swelling of ball-milled starch between hard and soft wheat or between samples within durum and soft wheats. However, a higher degree of swelling occurred in hard red winter than in hard red spring wheat, and the degree of swelling increased with ball-milling time.

Water-Absorption Index

Damaged starch plays a significant role in the water absorption of flour (Meredith 1966, Tara et al 1972, Evers and Stevens 1985, Bass 1988). Figure 3 shows that the WAI increased initially with

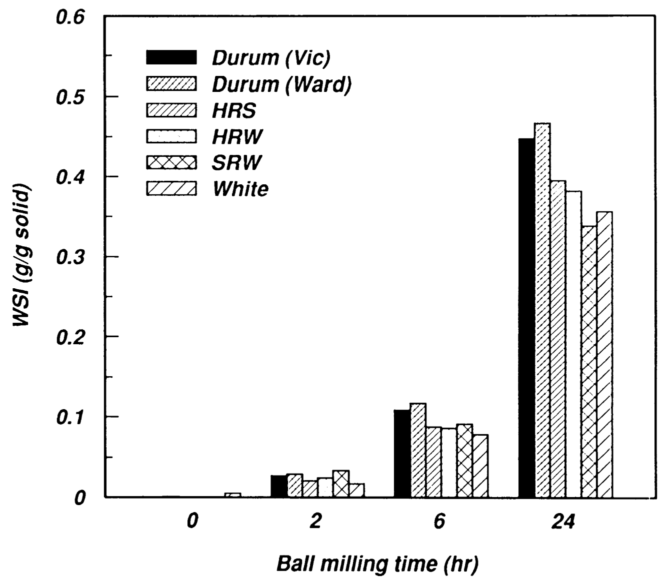

Fig. 4. Water-solubility index (WSI) of ball-milled starches of different wheat classes. HRS = hard red spring, HRW = hard red winter, SRW = soft red winter.

TABLE IV
Duncan's Multiple Range Test for Water-solubility index of Ball-Milled Wheat Starch

Factor	Mean Water-Solubility Index[a] (g/g of solid)
Wheat type[b]	
Durum	0.1577 a
Hard	0.1231 b
Soft	0.1148 b
Wheat sample[c]	
Ward durum	0.1712 a
Vic durum	0.1458 b
Hard red spring	0.1234 bc
Hard red winter	0.1229 bc
Soft red winter	0.1156 c
White	0.1140 c
Ball-milling time[d] (hr)	
24	0.3975 a
6	0.0930 b
2	0.0247 c
0	0.0012 d

[a] Means of each effect with same letter are not significantly different ($P = 0.05$).
[b] n = 16.
[c] n = 8.
[d] n = 12.

ball-milling time but either stayed the same or started to decrease as the ball milling continued. The 24-hr ball-milled starch showed either a similar or a lower WAI than the 6-hr ball-milled starch. The 6-hr ball-milled starch samples absorbed 5.5 to 6.5 times their weight in water. These results confirm the findings of previous researchers (Williams 1969, Meuser et al 1978).

The WAI of ball-milled starch showed the following trend with respect to wheat type: hard wheats had higher WAIs than soft wheats, which had higher WAIs than durum wheats. However, the difference in the WAI between hard and soft wheats (Table III) was not significant. Within the same wheat type, only soft wheat showed a significant difference between samples; soft red winter wheat starch showed a higher WAI than white wheat starch.

Water-Solubility Index

The WSI of starch increased with ball milling (Fig. 4). Durum wheat starch showed the highest WSI, followed by hard wheat and soft wheat starch. However, no significant difference was found between hard and soft wheat starch (Table IV). Also, there were no significant differences in the WSI between samples of the same wheat type except for durum: Ward durum showed a higher WSI than Vic durum.

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