Effects of Varying Weight Ratios of Large and Small Wheat Starch Granules on Experimental Straight-Dough Bread

Seok-Ho Park, Okkyung K. Chung, and Paul A. Seib

ABSTRACT

One commercial bread wheat flour with medium strength (11.3% protein content, 14% mb) was fractionated into starch, gluten, and water-soluble fractions by hand-washing. The starch fraction was separated further into large and small granules by repeated sedimentation. Large (10–40 μm diameter) and small (1–15 μm diameter) starch fractions were examined. Flour fractions were reconstituted to original levels in the flour using composites of varying weight percentages of starch granules: 0% small granules (100% large granules), 30, 60, and 100% (0% large granules). A modified straight-dough method was used in an experimental baking test. Crumb grain and texture were significantly affected. The bread made from the reconstituted flour with 30% small granules and 70% large granules had the highest crumb grain score (4.0, subjective method), the highest peak fineness value (1,029), and the second-highest elongation ratio (1.55). Inferior crumb grain scores and low fineness and elongation ratios were observed in breads made from flours with starch fractions with 100% small granules or 100% large granules. As the proportion of small granules increased in the reconstituted flour, it yielded bread with softer texture that was better maintained than the bread made from the reconstituted reference flour during storage.

Regarding the effect of starch granule size on baking potential, there are seemingly contradictory views on the effects of small B-type granules in breadmaking: 1) B-type granules are beneficial (Hayman et al 1998b; Sahilstrom et al 1998; Van Vliet et al 1992); 2) B-type granules are detrimental (Ponte et al 1963; D’Appolonia and Gilles 1971; Kulp 1973); 3) B-type granules have little effect (Hoseney et al 1971); and 4) B-type granules should be in optimum proportion with A-type granules for producing the best quality bread (Soulaka and Morrison 1985b; Lelièvre et al 1987; Park et al 2004).

Van Vliet et al (1992) suggested that when the starch granules were much larger than the thickness of the gas-cell wall in dough, their presence resulted in much higher stress locally than average and, in turn, this stress could induce instability of gas cells, implying that the large starch granules are the cause of instability of the gluten film, more so than small starch granules. Coalescence would occur as a result, and poor crumb grain would be generated (Hayman et al 1998b; Van Vliet et al 1992). Sahilstrom et al (1998) reported that B-type granule content varied from 10 to 39% by volume in eight bread wheat flours, and larger loaves of bread were produced with flours containing more B-type granules (2–2.3 μm).

On the other hand, small wheat starch granules also have been reported to cause detrimental effects. Ponte et al (1963) observed that wheat starch granule size distribution and the extent of starch damage were inversely correlated with the breadmaking functionality of wheat starches. D’Appolonia and Gilles (1971) reported that granule size of wheat starches did not have a significant effect on loaf volume when the bread was made from a gluten-starch blend, but small starch granules showed a substantial decrease in loaf volume when the blend contained the water-soluble starches. Small starch granules showed a lower baking potential than the un fractionated (mixture of large and small) granules, regardless of the source or method of preparation of the starch (Kulp 1973). However, small-granule wheat starch exhibited very little effect on loaf volume or water absorption but shortened the mix time compared with the control flour when it was reconstituted with gluten and water-soluble starches (Hoseney et al 1971).

An optimum proportion of B-type granules (25–35% by weight of total starch) in a blend produced the largest loaf of bread when Soula and Morrison (1985b) used protease-prepared starch from cracked wheat and beyond the optimum point the bread volume decreased. However, there was a different optimum starch size for a given protein level when a starch-gluten blend containing sugar and yeast was used for breadmaking (Lelièvre et al 1987). When a gluten-starch blend had a low gluten content, small starch granules were required to obtain optimum crumb grain and loaf volume.

1 Cooperative investigations, United States Department of Agriculture—Agricultural Research Service (USDA-ARS) and the Department of Grain Science and Industry, Kansas State University. Contribution No. 04-047-J from the Kansas Agricultural Experiment Station, Manhattan, KS 66506.
2 Research chemist, USDA-ARS, Grain Marketing and Production Research Center, Manhattan, KS 66502.
3 Supervisory research chemist, USDA-ARS, Grain Marketing and Production Research Center, Manhattan, KS 66502.
4 Professors, Department of Grain Science and Industry, Kansas State University, Manhattan, KS 66506.
5 Corresponding author. Phone: 785-776-2703. Fax: 785-537-5534. E-mail: okchung@gmprc.ksu.edu

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They found that small to intermediate size granules of wheat starch granule size on the rheological properties of flour-flours containing a weight percent of B-type granules ranging of B-type granules in starch of various wheat cultivars: the wheat relationship between the crumb grain scores and the weight percent Our previous study (Park et al. 2004) observed a polynomial reduced higher amylograph pasting peak and farinograph dough increased resistance to extension. Small granules (<5 μm) produced higher amylograph pasting peak and farinograph dough weakening, whereas the intermediate-size fraction of granules (5–16 μm) accelerated dough development and stability of dough. Disagreement concerning the effect of wheat starch granules and their size on breadmaking functionality could be due to various methods of starch isolation, fractionation, and drying, and also different baking techniques used by various researchers (Hoseney et al. 1971; Leliever et al. 1987; Sebecic and Sebecic 1995a; Park et al. 2004). However, it has been recognized that the granule size distribution of wheat starch is an important characteristic due to the different chemical and physical properties of large and small granules, which in turn influence the final characteristics of wheat-based products (Seib 1994; Raeker et al. 1998; Peng et al. 1999; Stoddard 1999; Chiotelli and Le Meste 2002).

The objective of this study was to investigate the effects of the granule size of wheat starch on the crumb grain and texture of bread by the straight-dough method using a direct approach of fractionation and reconstitution rather than the indirect statistical evaluation of wheat samples containing various starch size distributions.

**MATERIALS AND METHODS**

Materials

A commercially untreated bread wheat flour with medium protein (11.3% protein content, 14% mb) was selected for fractionation and reconstitution studies to avoid any additional effects from nonstarch flour constituents such as proteins that might have different effects of either improvement or impairment on the bread quality, depending on the different ratios of small to large starch granules in reconstituted flour. If the baking potential of starting flour is either extremely good (strong) or poor (weak), depending on flour protein quality, the effects of different size starch granules may be masked by other factors. Other baking materials included malt, shortening, and instant dry yeast from Cargill Flour Milling Co. (Wichita, KS), Bunge Foods (Bradley, IL), and Fleischmann’s Foods (Portland, OR), respectively.

**Proximate Analyses**

Flour, ash, and moisture contents were measured by Approved Methods 08-01 and 44-15A (AACC 2000), respectively. Flour protein (N × 5.7) content was determined by Approved Method 46-30 (AACC 2000) for combustion using a nitrogen determinator (Leco Corp., St. Joseph, MI).

Fractionation and Reconstitution of Flours

Flour (11.3% protein, 14% mb) was fractionated into starch, gluten, and water solubles by the hand-washing method of Finney et al. (1982) with modifications of Al-Obaidy (1986) and Miller and Hoseney (1999). Flour (300 g, 14% mb) was mixed to optimum with distilled water (=194 mL) using a 300-g mixer (National Mfg. Co., Lincoln, NE). The dough was placed into a 2L beaker with 200 mL of chilled, distilled water for 15 min, after which it was gently kneaded and dispersed by one rubber-gloved hand. Then, supernatant water separating from the dough mass was decanted. The kneading and washing of the elastic mass were repeated with chilled, distilled water (2 × 100 mL, 4 × 75 mL, and then 4–6 × 50 mL). The starch suspensions separated from the cohesiveness of gluten proteins were combined and strained through a nylon bolting cloth (75 μm openings) to remove fine fiber (bran and aleurone particles) and a small portion of other unknown particles. Those parts were quantified and amounted to <2% of flour solids; they were not included in reconstitution. The starch suspension was centrifuged at 2,000 × g for 15 min and the supernatant (water solubles) was frozen, lyophilized, and ground with a mortar and pestle. After the supernatant was decanted, the gray-colored tailings were scraped off the top of the white starch layer using a spatula. These steps of suspending in water (=150 mL in 250-mL centrifuge bottle), centrifuging, and scraping were repeated until there were no tailings visible on the top of the prime starch. After each washing and centrifuging step, the top supernatant liquid layer was discarded. The tailings that gathered from each scraping were resuspended in water (150 mL), centrifuged, and the tailings separated from starch. The wet gluten was rested 1 hr, then frozen, lyophilized, and ground with a household coffee mill to pass a 100-mesh sieve (149 μm openings) (Shogren et al. 1969).

The starch fractions (=175 g, db) were further separated into large and small granules by repeated suspension in water (1.8L) followed by sedimentation (Soulaka and Morrison 1985b). The large granules were allowed to settle for 1.5 hr in two 2L beakers containing a fluid depth of 18 cm. The supernatant was decanted and the sediment was resuspended and settled as before. This procedure was repeated five times. The final sediment contained mostly large A-type granules, and the combined supernatants contained mostly small B-type granules. The B-type granule starch was recovered by centrifugation (4,000 × g, 15 min) and the sediments were frozen. After lyophilization, the dry starch was ground lightly with a mortar and pestle. These starch fractions were rehydrated in the fermentation chamber to 11% moisture before they were used in reconstitution experiments. The sizes of large and small starch fractions were examined using a Microtrac S3000 analyzer (Microtrac Software Co., Wyominging, PA) equipped with the Tri-laser system.

For reconstituting the fractions, the original weight was maintained for the gluten, water solubles, and starch fractions, using starch composites containing variable amounts of large and small starch granules. None of the reconstituted flours, except one, included the tailings fraction. All reconstituted flours (a total of 230 g/batch) were blended thoroughly on tumbling equipment (Norton, Akron, OH) for 1 hr.
Breadmaking Procedure
A modified straight-dough baking method (100 g of flour, 14% mb) was used (Finney 1984) (Approved Method 10-10B, AACC 2000). The bread formula contained 100 g of flour, 11 mL of a solution containing 6 g of sucrose and 1.5 g of sodium chloride, 5 mL of an aqueous malt mixture (0.25 g of dried malt), dry active yeast (1.0 g), melted shortening (3 g), and 1 mL of ascorbic acid solution (5 mg). The detailed baking procedure is described in a previous report (Park et al. 2004). The mixed doughs of reconstituted flours were proofed to 7.1 cm, the same proof height of the dough prepared with the original flour.

Evaluation of Crumb Grain and Crust Thickness
Crumb grain characteristics were evaluated subjectively and objectively. Crumb grain score was determined by a highly trained baking expert as described in previous reports (Park et al. 2004). Crumb fineness, elongation ratio, and crust thickness were determined by CrumbScan software (v. 3.0) developed by the American Institute of Baking (Manhattan, KS).

Evaluation of Crumb Firmness
Crumb firmness was determined using a texture analyzer (model TA-XT2, Stable Micro Systems, Surrey, UK) equipped with an acrylic probe (3.7 cm diameter) after 1, 3, and 5 days of bread storage. Two slices (1 cm thickness/slice) of bread were stacked on top of each other and the center portion of the slice was compressed at 1.7 mm/sec and a distance of 25% of the thickness of the two slices.

Fig. 2. Bread loaves baked with original flour and reconstituted flours. A, original flour; B, reconstituted flour; C, reconstituted without tailings; D, starch-interchanged flour with 100% tailings starch; E, starch-interchanged flour with 0% small (100% large) starch granules; F, starch-interchanged flour with 30% small (70% large) starch granules; G, starch-interchanged flour with 60% small (40% large) starch granules; H, starch-interchanged flour with 100% small (0% large) starch granules.

<table>
<thead>
<tr>
<th>TABLE I</th>
<th>Fractions in Reconstituted Flours (dwb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flours</td>
<td>Small Granules</td>
</tr>
<tr>
<td>B, Reconstituted</td>
<td>12.2 (14.9)</td>
</tr>
<tr>
<td>C, Reconstituted without tailings</td>
<td>13.9 (17.0)</td>
</tr>
<tr>
<td>Starch-interchanged</td>
<td>24.5 (30.0)</td>
</tr>
<tr>
<td>E, 0% small granules</td>
<td>49.1 (60.0)</td>
</tr>
<tr>
<td>F, 30% small granules</td>
<td>81.8 (100.0)</td>
</tr>
<tr>
<td>G, 60% small granules</td>
<td>81.8 (100.0)</td>
</tr>
<tr>
<td>H, 100% small granules</td>
<td>81.8 (100.0)</td>
</tr>
</tbody>
</table>

Statistical Analysis
A completely randomized experimental design was used with at least two replicates of all experiments, and the data were analyzed by a statistical analysis system (v. 8.0, SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Flour and Starch Fractionations
When 300 g of bread wheat flour with an intermediate protein level of 11.3% (14% mb) was fractionated, it yielded four main fractions (14% mb): water solubles (14.1 g), tailings (27.2 g), gluten (37.4 g), and starch (202.8 g). The recovery of flour solids in the four fractions was 94%, with most of the loss due to the discarded fine fiber and other unknown particles.

Separated large and small starch granules were subjected to laser particle-size analysis to verify the efficiency of separation. The separation was successful based on the particle-size results of Microtrac S3000 analysis (Fig. 1). The fraction with large starch granules consisted mostly of starch granules >10 μm in diameter, and those of the fraction with small granules were mostly <10 μm in diameter.

Reconstitution
Flours were reconstituted to original composition with the tailings fraction (B) or without the tailings fraction (C), and four different starch composites, containing 100, 60, 30, and 0% small starch granules (E–H) (Table I). One flour (D) was reconstituted with 100% tailings starch (Fig. 2), but it will be omitted from further discussion because of poor baking characteristics. The
starch-interchanged flours contained (by weight of dry solids) 81.8% starch, 13.3% gluten, and 4.9% of water solubles, yet none of the tailings fraction (Table I). The reconstituted flour B contained 10% tailings, whereas the other remaining reconstituted flours had 10% tailings fraction being replaced by the additional starch (i.e., in the second reconstituted flour [C] and the four starch-interchanged flours [E–H]) (Table I). Although the tailings fraction contained only 86% starch, it was excluded from the reconstitution process so that the ratio of large to small granules was more easily controlled. Previously, it was reported that the flour reconstituted with gluten, water solubles, and tailings fraction produced only a one-half-size loaf of bread compared with the unfractionated original flour (Hoseney et al 1971).

**Breadmaking Properties of Reconstituted Flours**

In spite of carefully managed fractionation and reconstitution processes, reconstituted flour B did not show the same baking properties as did original flour A (Table II, Fig. 2). Reconstituted flour B required lower water absorption and mix time and produced a significantly smaller loaf of bread with thicker crust and similar or better crumb grain score and other crumb characteristics than the original flour (Table II). It is speculated that even some slight damage to flour components during the fractionation process could magnify impairment of breadmaking quality such as loss of bread volume in the weak dough or relatively low-protein dough. In addition, the loss of fine fiber and some solubles in the starch washings might have reduced loaf volume. Therefore, we decided to use reconstituted flour B as the reference standard flour for measuring the effect of absence of tailings starch in reconstitution (flour C), and flour C as the reference standard flour for investigating the effects of starch granule size distribution on breadmaking quality by varying the weight ratios of large A-type to small B-type granules. Comparing the starch-interchanged loaves to the loaf of flour reconstituted without tailings (C) should give a better comparison because starch-interchanged flours (E–H) did not contain the tailings fractions. The protein contents of reconstituted flour were all nearly the same as the original flour (Table II).

The reconstituted reference flour B required significantly greater water absorption than the reconstituted reference flour C because flour B contained the tailings fraction, which is rich in pentosans (D’Appolonia and MacArthur 1975) that are recognized to have a high water-holding capacity (Shogren et al 1987).

Reconstituted flour E with all large starch granules required absorption and mixing requirements similar to those of flour C. Bake absorption and mix time varied significantly with starch granule distribution; the absorption increased and bake mix time decreased with an increase in small granules.

Bake absorption increased by nearly 5 percentage points by interchanging all large granules with small granules (Table II, flour E vs. H). Kulp (1973) previously reported that small starch granules have a higher water-binding capacity due to the high specific surface area.

**TABLE II**

<table>
<thead>
<tr>
<th>Flours</th>
<th>Protein (%)</th>
<th>Absorp (%)</th>
<th>Mix (min)</th>
<th>Crumb Characteristicsa</th>
<th>Crust Thickness (cm)</th>
<th>Loaf Vol (cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CGS²</td>
<td>ER³</td>
<td></td>
</tr>
<tr>
<td>A, Original</td>
<td>11.3a</td>
<td>61.8a</td>
<td>6.0a</td>
<td>3.4b</td>
<td>826c</td>
<td>0.25c</td>
</tr>
<tr>
<td>Reconstituted</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B, With tailings</td>
<td>11.3a</td>
<td>59.2b</td>
<td>5.8a</td>
<td>3.8ab</td>
<td>966b</td>
<td>0.30b</td>
</tr>
<tr>
<td>C, Without tailings</td>
<td>11.1a</td>
<td>55.0d</td>
<td>6.2a</td>
<td>3.0b</td>
<td>1,000a</td>
<td>0.33a</td>
</tr>
<tr>
<td>Starch-interchanged</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E, 0% small granules</td>
<td>11.1a</td>
<td>55.4cd</td>
<td>6.1a</td>
<td>3.0b</td>
<td>939b</td>
<td>0.30b</td>
</tr>
<tr>
<td>F, 30% small granules</td>
<td>11.2a</td>
<td>55.6ed</td>
<td>5.8a</td>
<td>4.0a</td>
<td>1,029a</td>
<td>0.33a</td>
</tr>
<tr>
<td>G, 60% small granules</td>
<td>11.3a</td>
<td>57.1c</td>
<td>4.6b</td>
<td>3.6ab</td>
<td>948b</td>
<td>0.32ab</td>
</tr>
<tr>
<td>H, 100% small granules</td>
<td>11.3a</td>
<td>60.2ab</td>
<td>4.9b</td>
<td>2.5c</td>
<td>778d</td>
<td>0.33a</td>
</tr>
<tr>
<td>LSD³</td>
<td>0.3</td>
<td>1.9</td>
<td>0.8</td>
<td>0.5</td>
<td>46</td>
<td>0.03</td>
</tr>
</tbody>
</table>

* Mean values of two replicates, expressed on a 14% moisture basis. Means in the same column with the same letter are not significantly different.

² Crumb grain score, determined subjectively (0 = unsatisfactory, 4.0 = satisfactory).

³ Elongation ratio.

⁴ Least significant difference (P = 0.05).

Fig. 3. Crumb grain of breads (see Fig. 2) from (I) reconstituted flour (bread B); and (II) reconstituted flour without tailings starch (bread C).
Mix time decreased with the increasing proportions of small starch granules (Table II). As stated before, the small granular wheat starch has \( \approx 3 \times \) larger specific surface area than the large granular wheat starch (Meredith 1981; Soulaka and Morrison 1985a). The small granules could interact more intimately as filler particles with the continuous gluten phase in dough, which causes a corresponding increase in resistance to mixing.

For this study, it was hard to assess the loaf volume potential of each reconstituted flour containing different starch composites of various size distributions because we proofed each dough to a constant proof height of 7.1 cm. By doing so, we could see the changes in crumb grain structure affected mainly by the starch granule sizes, but not by other factors such as the loaf volume. Nonetheless, some differences in loaf volume and appearance of bread baked from reconstituted flours B versus C and flour C versus starch-interchanged flours E–H are apparent (Fig. 2, Table II). The break and shred of bread G was the largest (Fig. 2) and so was the loaf volume (Table II). The high swelling properties of small granules may contribute to the increase in loaf volume. However, bread H, made from the reconstituted flour with a starch composite of 100% small granules was smaller than bread G. It may be speculated that too much of a rapid demand on water from the small granules during oven spring may incur imbalance of water distribution in the dough (starch and gluten) and, as a result, destabilize air cells and produce a small loaf of bread with poor crumb grain structure.

Appearances of bread crumb grain are shown in Figs. 3–5. The crumb grain scores of starch-interchanged flours E–H ranged from 2.5 to 4.0 compared with 3.0 for reconstituted reference flour C (Table II). At first glance, the crumb grain of bread C looked superior to bread B (Fig. 3). Actually, bread C had a finer crumb grain than bread B, but much smaller elongation ratio than bread I. Analysis by a baking expert put more value on lacy and elongated cell structure rather than cake-like crumb structure. Bread B also had a thinner crust than bread C.

The crumb grain score was the highest with the bread made from reconstituted flour F containing a starch composite of 30% small and 70% large starch granules, and the lowest for the bread

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**Fig. 4.** Crumb grain of breads (see Fig. 2) from starch-interchanged flours with (III) 0% small (100% large) starch granules (bread E) and (IV) 30% small (70% large) starch granules (bread F).

**Fig. 5.** Crumb grains of breads (see Fig. 2) from starch-interchanged flours with (V) 60% small (40% large) starch granules (bread G) and (VI) 100% small (0% large) starch granules (bread H).
from reconstituted flour H containing 100% small starch granules (Table II). The crumb grain of bread F showed the best combination of elongation, as well as small cells, in comparison with the other loaves (Figs. 3–5). This was verified objectively by the elongation ratio and fineness values measured by CrumbScan software (Table II). Those results suggested that there was a range of optimum weight ratio of small to large starch granules for producing bread with good crumb grain score; the optimum weight percentage of small starch granules was >30% in this investigation. The current results are in general agreement with our previous report (Park et al 2004) that the wheat cultivars with an optimum range (19.8–22.5%, excluding tailings starch) of small granule weight percentages produced breads with the best crumb grain scores. As mentioned earlier, tailings compose >10% (dry basis) of flour and consist of mostly small starch granules.

Hayman et al (1998b) observed more open crumb grain for bread made with potato starch, where granules were two to three times larger than A-type wheat starch. They also reported that bread made from flour with 100% large wheat starch granules contained more open grain and thicker cell walls than the bread baked with 100% small wheat starch granules. According to Van Vliet et al (1992) and Hayman et al (1998b), the large starch granules in bread dough could produce a much higher stress locally on thin-walled gas cells and induce instability, resulting in coalescence of cells and thereby producing enlarged gas cells and poor crumb grain. However, as discussed previously (Park et al 2004), it does not seem to always be true. Our results are in only partial agreement with those of Hayman et al (1998b) because our bread baked with reconstituted flour H, containing the starch fraction of 100% small starch granules, showed crumb characteristics as poor as, or even worse than, the bread from flour E containing 100% large starch granules (Table II, Fig. 4 [III] and Fig. 5 [VI]). Crumb fineness score of bread baked with 100% small starch granules was only 778, whereas other breads baked with 0, 30, and 60% small granules scored 939, 1,029, and 948, respectively. Based on our results, the major driving factor of air cell coalescence producing large air cells does not seem to be dependant only on the size of starch granules.

The poor crumb grain of bread produced with the flour of 100% small wheat starch granules may be the result of less availability of amylose to interact with the gluten matrix (Martin and Hoseney 1991; Park et al 2004) which provides stable "film" during baking compared with bread baked with large granules containing more amylose. If this is the only reason for poor crumb grain, it can be expected that 0% small granules (100% large granules) should produce a bread with the best crumb grain appearance due to the higher amylose content in large granules. However, that was not the case in this study. The bread baked with reconstituted flour E containing 100% large granules had a mediocreme crumb grain score with a fair crumb fineness score (Table II, Fig. 4 [III]). Considering that bread dough should have an optimal viscoelastic property, it can be presumed that an extra stiff or overly loose starch-gluten matrix system would have an adverse effect on the stability of gas cells. Van Vliet et al (1992) proposed that bulk rheological properties of dough would affect overall gas cell stability.

Some other possible reasons for producing bread with poor crumb grain with 100% small granules may be due to the different swelling or water-holding capacities between large and small starch granules. MacRitchie (1976) and Gan et al (1990, 1995) proposed that gas cells are stabilized by a continuous liquid film on a starch-protein matrix. During the early stages of baking, small starch granules with higher surface area and swelling power would absorb water more quickly than large starch granules at a certain temperature. At this stage, water could become limited to the liquid film and the imbalance of water availability in the dough could cause collapse of the liquid film around some gas cells, destabilizing the gas cells. Hayman et al (1998a) observed no apparent differences in the number of gas cells between doughs producing good and poor crumb grain until after the first punch, but differences in crumb grain were found after 12 min of baking.

Also, as observed in previous microscopic studies (Sandstedt et al 1954; Khoo et al 1975; Bechtel et al 1978) on the structure of bread cell walls, starch granules are embedded in a continuous protein matrix. The extra surface area of the small starch granules gives increased contact with the gluten film. The increased contact could give a stiffer gas cell wall (less gluten film is available to expand) and break open the cell wall prematurely as the dough expands and changes from a foam to a sponge.

**Bread Firmness**

Bread made with the reconstituted reference flour B was significantly softer than the loaves made from the reconstituted reference flour C as well as the starch-interchanged flours E–H (Table III). Reconstituted flour B contained starch tailings, whereas neither flour C nor the starch-interchanged flours did. As stated earlier, the starch tailings fraction contains pentosans that strongly absorb water (Slade et al 1993) and thus the bread crumb of the loaf made from reconstituted flour B retained more moisture, as shown by the loaf weight (Table III). Extra moisture retards firming of bread crumb (Rogers et al 1988).

Bread made with reconstituted flour H with 100% small wheat starch granules was significantly softer than that made with reconstituted flour E with 100% large wheat starch granules (Table III). Three reasons may be given for that difference. 1) Small wheat starch granules would exude less amylose during baking and thus less amylose between starch and denatured gluten would reduce cross-linking of the starch-gluten network (Martin and Hoseney 1991). 2) Small granular wheat starch contains more lipids than the large granules, which may decrease firmness. Finally, 3) higher swelling power of small wheat starch granules may increase retention of moisture in the bread crumb.

**Table III**

<table>
<thead>
<tr>
<th>Flours</th>
<th>Loaf Weight (g)</th>
<th>Day 1</th>
<th>Day 3</th>
<th>Day 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Original</td>
<td>148.9a</td>
<td>394d</td>
<td>746d</td>
<td>1,175d</td>
</tr>
<tr>
<td>Reconstituted</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B. With tailings</td>
<td>146.8a</td>
<td>534c</td>
<td>933c</td>
<td>1,296c</td>
</tr>
<tr>
<td>C. Without tailings</td>
<td>144.1b</td>
<td>696a</td>
<td>1,276a</td>
<td>1,742a</td>
</tr>
<tr>
<td>Starch-interchanged</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E, 0% small granules</td>
<td>143.3b</td>
<td>700a</td>
<td>1,261a</td>
<td>1,720a</td>
</tr>
<tr>
<td>F, 30% small granules</td>
<td>143.0b</td>
<td>635b</td>
<td>1,178b</td>
<td>1,684ab</td>
</tr>
<tr>
<td>G, 60% small granules</td>
<td>143.8b</td>
<td>537c</td>
<td>1,135b</td>
<td>1,602b</td>
</tr>
<tr>
<td>H, 100% small granules</td>
<td>144.2b</td>
<td>498c</td>
<td>1,112b</td>
<td>1,517b</td>
</tr>
<tr>
<td>LSDb</td>
<td>2.4</td>
<td>52</td>
<td>80</td>
<td>116</td>
</tr>
</tbody>
</table>

a Mean values of two replicates. Means in the same column with the same letter are not significantly different.

b Least significant difference (P = 0.05).
CONCLUSIONS

Crumb grain of bread baked from the reconstituted flours containing starch composites of various granule sizes was the best when bread was made with a large-to-small ratio of 7:3 (w/w) wheat starch granules, based on both subjective and objective measurements. The higher the proportion of small granular wheat starch in flour, the softer the bread crumb grain was maintained during storage.

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LITERATURE CITED


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