

Role of Starch Granules in Controlling Expansion of Dough During Baking

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ABSTRACT

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The role of starch granules in the expansion of doughs during baking was investigated using artificial flours made from dry vital wheat gluten and wheat starch, potato starch, or tapioca starch. The three starches were selected because of their diverse gelatinization properties. Baking tests on flour from tapioca starch gave the largest loaf volume and the most extensive postbaking shrinkage. Potato starch flour gave the smallest volume and the least shrinkage. Amylograph test data, dough expansion under decreased pressure, progress of expansion during baking, and scanning electron microscopy revealed the role starch granules play in ideal baking

conditions. Starch granules should not gelatinize early in the baking cycle as potato starch does but should gelatinize later in the baking cycle as wheat starch does. This prevents early setting of the dough which inhibits expansion. Starch granules should not disrupt and fuse together during gelatinization as tapioca starch does, forming an impermeable gas membrane. Granules should gelatinize individually as wheat starch does, causing a disruption of cell membranes which prevents shrinkage of the loaf during cooling after baking.

Past research on the role of flour components on the baking properties of flour have focused on the proteins. In this context, differences in the expansion of dough during the baking phase are generally attributed to differences in protein content and quality. However, on a purely quantitative basis, the role of wheat starch in the unique breadmaking ability of wheat flour should not be overlooked. Starch has several distinct roles in the breadmaking process. It is the substrate for the amylases that produce fermentable sugars for yeast fermentation and it serves as a reservoir for water absorption and as a diluent for gluten, thereby contributing to the optimal viscoelastic properties of the dough (Burhans and Clapp 1942, Sandstedt et al 1954, Sandstedt 1955). A comparison of the unique properties of wheat starch with those of other starches was made in breadmaking studies conducted by Hosoney et al (1971) on artificial flours made from dry gluten and wheat, corn, milo, oat, rice, and potato starches. Hayman et al (1998a) found that starch granule size was at least one of the factors that affected the crumb grain of bread. They also showed that gas cells coalesced during the early stages of baking, suggesting the crucial role of starch granules in controlling the expansion of dough during baking. Our study was conducted using three starches, wheat, potato, and tapioca, that are distinctly different in gelatinization properties and in size. Our goal was to further clarify the effect of their properties on the expansion of dough.

MATERIALS AND METHODS

Potato starch (18.6% moisture; 0.128% protein [$N \times 5.7$]), tapioca starch (13.9% moisture, 0.162% protein), wheat starch (12.9% moisture, 0.128% protein), and dry vital wheat gluten (5.7% moisture, 73.42% protein, 0.61% ash) were provided by Glico-Eisyoku Co. Ltd. (Tokyo). Compressed yeast was supplied by Oriental Yeast Co. (Tokyo). Salt and sucrose were commercial-grade.

Artificial flours were prepared by dry blending each of the three starches with gluten in the ratio 15.4 to 84.6%. Doughs contained 1,134 g of flour, 5% (flour basis) sugar, 2% salt, 3% yeast, and 65% water. Doughs were mixed in a Ken Mix Chef mixer KM-201 (Aiko Co. Ltd., Tokyo). Mixing time was 5 min at 170 rpm (speed no. 1) and 2 min at 220 rpm (speed no. 2). These conditions were selected as an optimum by a prebaking test. For bread baking, the doughs were fermented at 35°C for 30 min, divided into portions of 165 g, and molded according to Approved Method 10-10A (AACC

1995) after rounding and resting for 10 min. Doughs were proofed (35°C and 85% rh) to a height of 65 mm. Loaf volume was determined by rapeseed displacement. Oven spring was calculated by subtracting proof height from loaf height. A record of the internal appearance was obtained by photocopying the crumb of a loaf sliced into two equal parts.

Amylograms of the starches were obtained according to Approved Method 22-10 (AACC 1995) with minor modifications. The amount of starch used was 7% for tapioca and wheat, and 4% for potato. The temperature was raised to 93°C and held.

The change in height of the loaf with time during baking was read off a scale through the oven window at 3-min intervals. Shrinkage of the loaf during cooling. The volume of bread after removal from the oven was measured by rapeseed displacement at 3-min intervals for 60 min. To measure the expansion under reduced pressure, the dough formula was the same as for baking except the yeast was omitted. After mixing, the dough was rested for 30 min at 20°C, divided into portions of 35 g, and placed into a glass cylinder 30 mm in diameter. Separate samples were equilibrated for 15–20 min in water baths set at 35, 60, 65, 70, 75, and 80°C. The samples were cooled to 35°C and subjected to the extension test at a pressure of 45 mm Hg according to Hosomi et al (1992).

Scanning electron micrographs were obtained with an electron microscope (S-800 Hitachi). The bread samples were dried and coated with platinum under vacuum and viewed.

RESULTS AND DISCUSSION

Loaf volume, specific volume, and oven spring values in Table I show that bread containing tapioca starch had the highest volume and oven spring. Potato starch bread had the lowest volume and oven spring. All proofed doughs were the same height (65 mm) when placed in the oven. The external and internal crumb appearances of the three loaves are shown in Fig. 1. The loaf baked with tapioca starch had the highest vertical expansion and greatest shrinkage after cooling (T-S, T-G). The crumb texture was sticky and the cell membranes appeared to be adhesive. The loaf baked with wheat starch had a finer, more uniform grain (W-G) and softer texture. The gas cells in the crumb of the bread made with potato starch were smaller (P-G) and the gas membranes were thicker. The texture was like that of hard rubber.

Amylograms of the three starches (Fig. 2) showed that wheat starch had the highest amylograph pasting temperature (80°C), potato starch was next (60°C), and tapioca starch had the lowest (59°C). The latter two starches had the highest peak viscosity. Potato starch was still highest even at lower concentrations. The amylograph pasting temperature of potato starch at 7% concentration was the same as that shown in Fig. 2 for a 4% starch slurry.

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The time shift of dough expansion during baking (Fig. 3) showed when wheat starch bread and potato starch bread reached their maximum height. Wheat starch bread and potato starch bread reached maximum height at 10 min and 5 min, respectively. Tapioca starch bread showed a slow but definite rise at ≤ 16 min when it reached its highest level. Tapioca starch produced the largest loaf during baking.

Loaves baked with all three starches showed some shrinkage during cooling after baking (Fig. 4). The tapioca starch bread showed the greatest shrinkage (26 cm^3) at 21 min after removal from the oven. Loaves containing wheat starch showed the least shrinkage.

Expansion of the three doughs under reduced pressure was measured after heat treatment for 15–20 min at different temperatures (Fig. 5). Results showed that the tapioca starch bread dough heat-treated at 65°C had the greatest expansion, while wheat starch and potato starch breads had less expansion. At 35°C , wheat starch bread had the greatest expansion.

Scanning electron micrographs (Fig. 6) showed that the gas cell membranes of the tapioca starch bread had no identifiable starch

granules. In the wheat starch bread, the gas cell membranes contained starch granules visible on the surface. The granules were oval in shape and larger in size than those of raw wheat starch. The membranes of potato starch bread also contained individual starch granules on the surface.

CONCLUSIONS

Various roles of starch granules in the physical properties of wheat flour doughs have been reported (Burhans and Clapp 1942, Sandstedt et al 1954, Petrofsky and Hosenev 1995). The existence of a starch-gluten interaction cannot be denied. As far as the behavior of starch during breadbaking, gelatinization must play a key role. Baking results for artificial flours with potato, tapioca, or wheat starch, all of which have quite different gelatinization properties, should provide additional information for this role. During swelling and gelatinization, the starch granules in wheat flour doughs avidly absorb free water and some of the water that is liberated by the heat denaturation of gluten. Gelatinized starch in

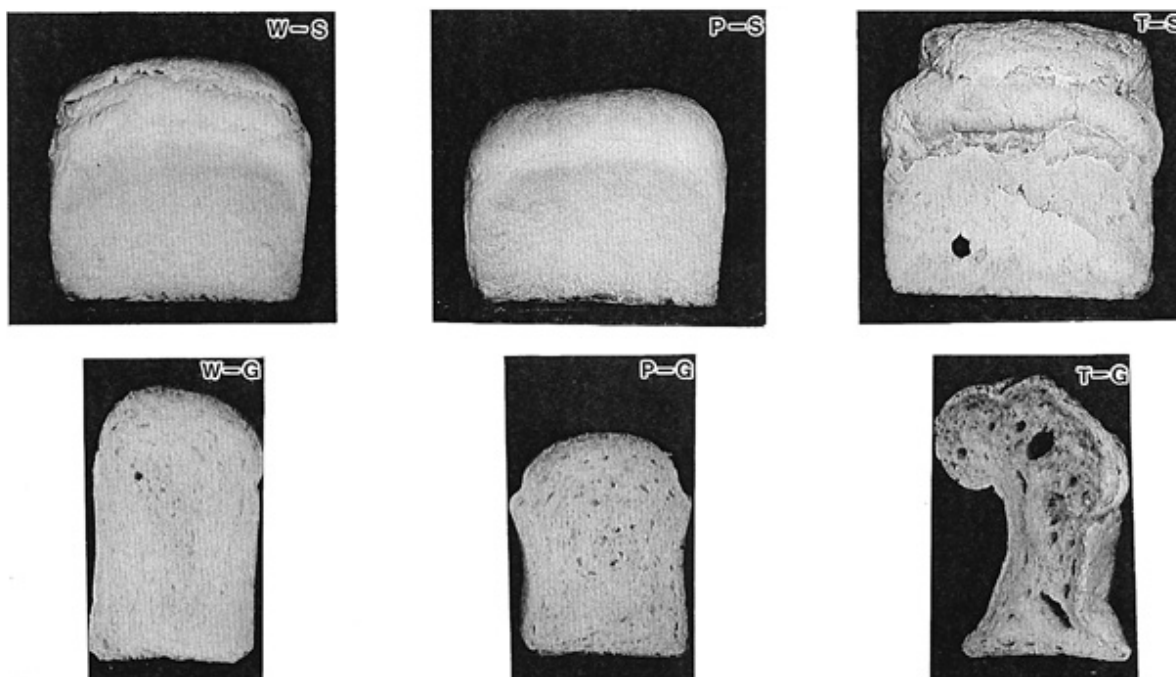


Fig. 1. Side views of loaves (S) and internal grain (G) of breads baked with reconstituted flour of vital wheat gluten and wheat starch (W), potato starch (P), or tapioca starch (T).

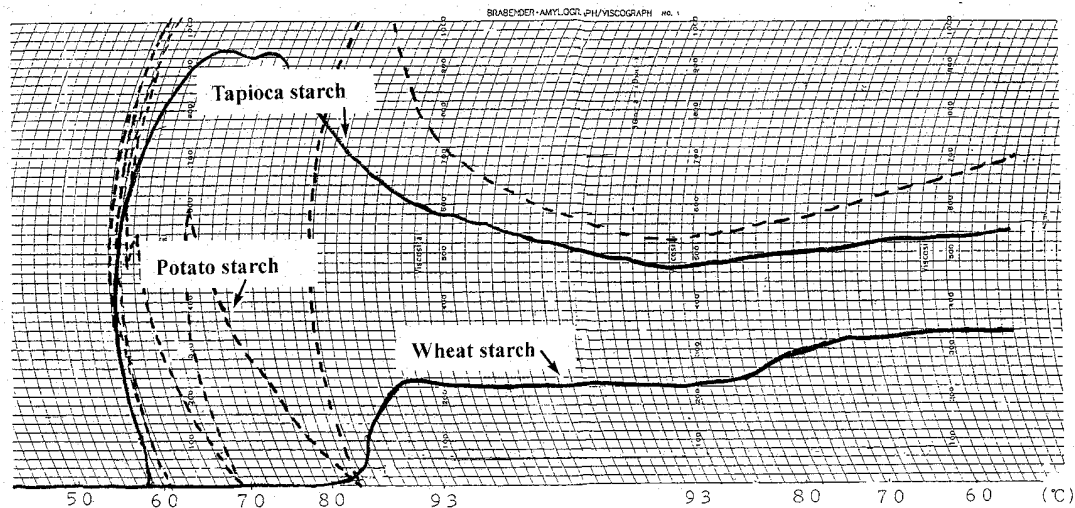


Fig. 2. Amylogram profiles of wheat, potato, and tapioca starches.

the dough, along with the gluten, form the membranes of the gas cells in bread crumb. During baking, the starch granules become flexible and undergo considerable deformation (Sandstedt et al 1954). When gelatinization takes place under conditions of limited water, as in dough, the gas membrane solidifies and sets while the starch granules maintain their integrity without fusing together.

After doughs were placed in the oven (Fig. 3), it was observed that the expansion of the wheat starch dough continued for 9 min and remained constant. On the other hand, in the potato starch and tapioca starch breads, most of the expansion occurred at ≤ 4 min (Fig. 3). The additional expansion time for the wheat starch dough is attributed to the higher gelatinization temperature of its starch. Tapioca starch bread continued to expand slowly at 5–15 min.

Dough made with tapioca starch remained extensible at ≤ 15 min when heat-treated at 70–80°C (Fig. 5). This allowed the dough to expand in the oven. Potato and wheat starch doughs showed the lowest extensibility at 65 and 70°C, therefore, they would set earlier than tapioca starch doughs. Potato and tapioca starches had sim-

ilar gelatinization temperatures (60°C). However, the state of the gelatinized granules in bread was quite different (Fig. 6). Scanning electron micrographs showed that potato starch granules retained their integrity, whereas tapioca starch granules lost their identity by fusing into a continuous mass. The shape and size of the loaf should be set after expansion terminates in the oven. The gas cell membranes of the tapioca starch bread appear to be impermeable but still retain extensibility. On cooling, such a loaf, which is gas discontinuous, will shrink due to negative internal pressure created by cooling. This behavior of tapioca starch on the expansion and break up of the granules seems to be similar to that observed in dough made from waxy starch by Ghiasi et al (1984). Loaves made with potato and wheat starch showed evidence of cracks in the gas cell membranes (Fig. 6), thus, they are gas continuous. This would minimize the postbaking shrinkage. The specific effect of potato starch was related to the size of starch granules (Hayman et al 1998b). This might be the result of poor interaction between starch granules and gluten.

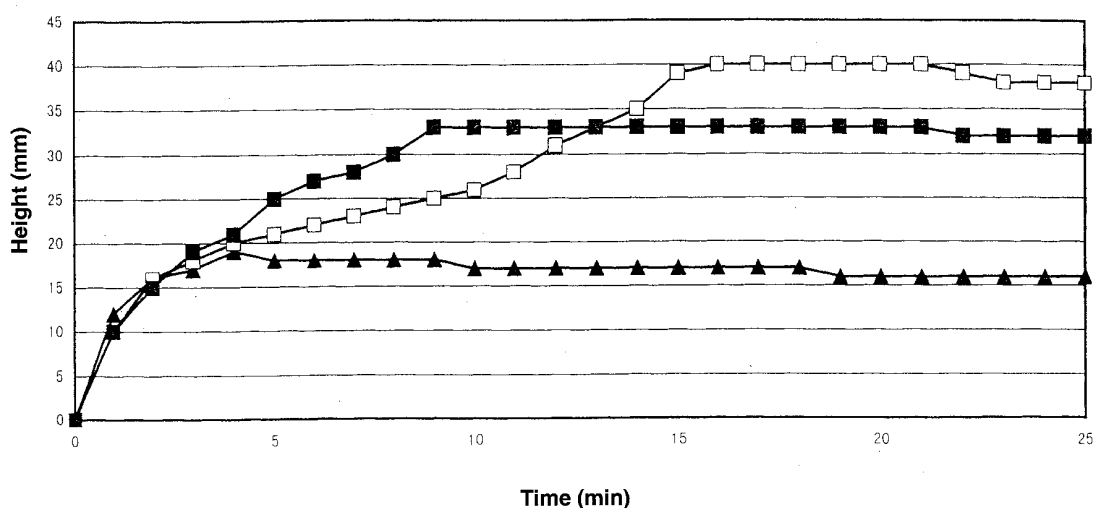


Fig. 3. Time shift of expansion of doughs during baking. Reconstituted flour with vital wheat gluten and wheat starch (■), potato starch (▲), or tapioca starch (□).

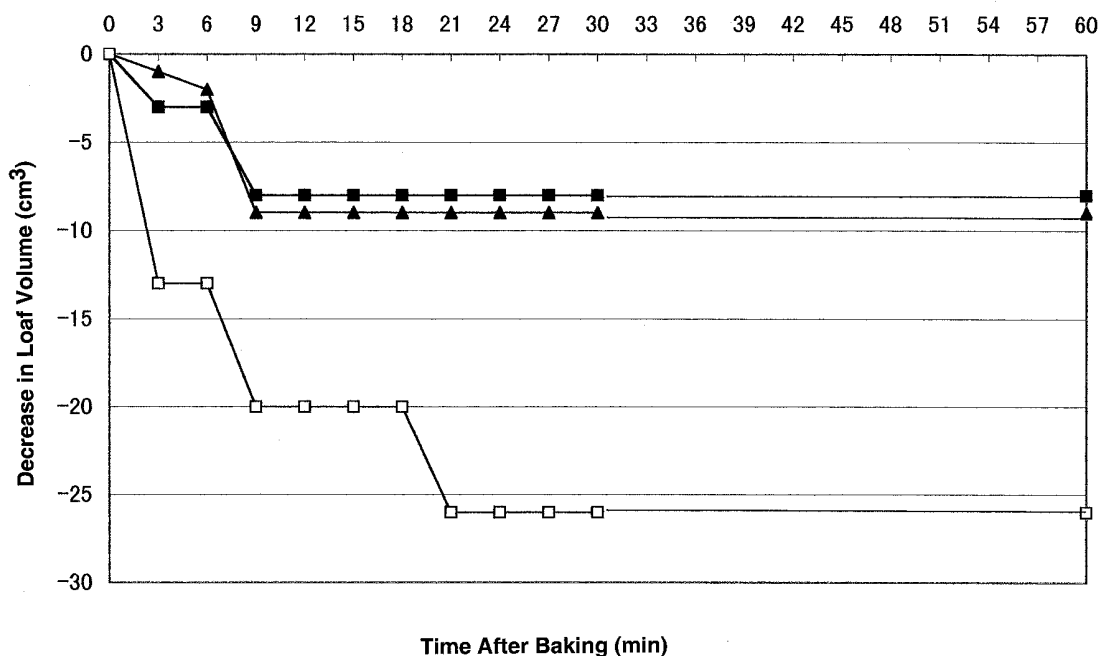


Fig. 4. Time shift of shrinkage of breads. Reconstituted flour with vital wheat gluten and wheat starch (■), potato starch (▲), or tapioca starch (□).

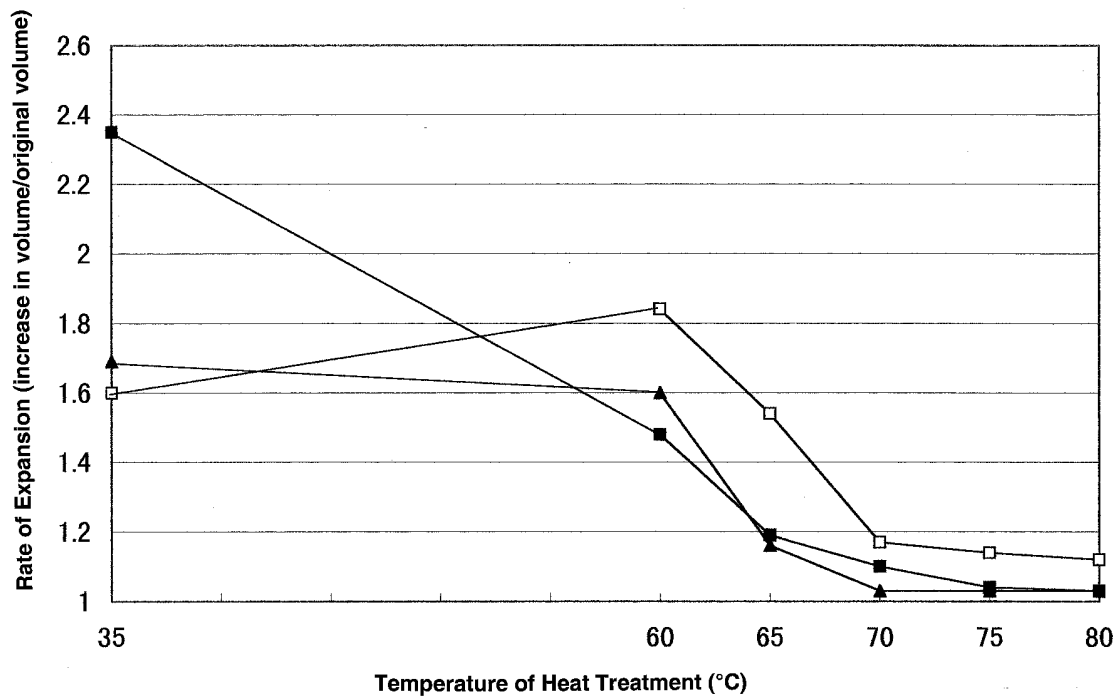


Fig. 5. Rate of dough expansion under reduced pressure after treatment at various temperatures. Reconstituted flour with vital wheat gluten and wheat starch (■), potato starch (▲), or tapioca starch (□).

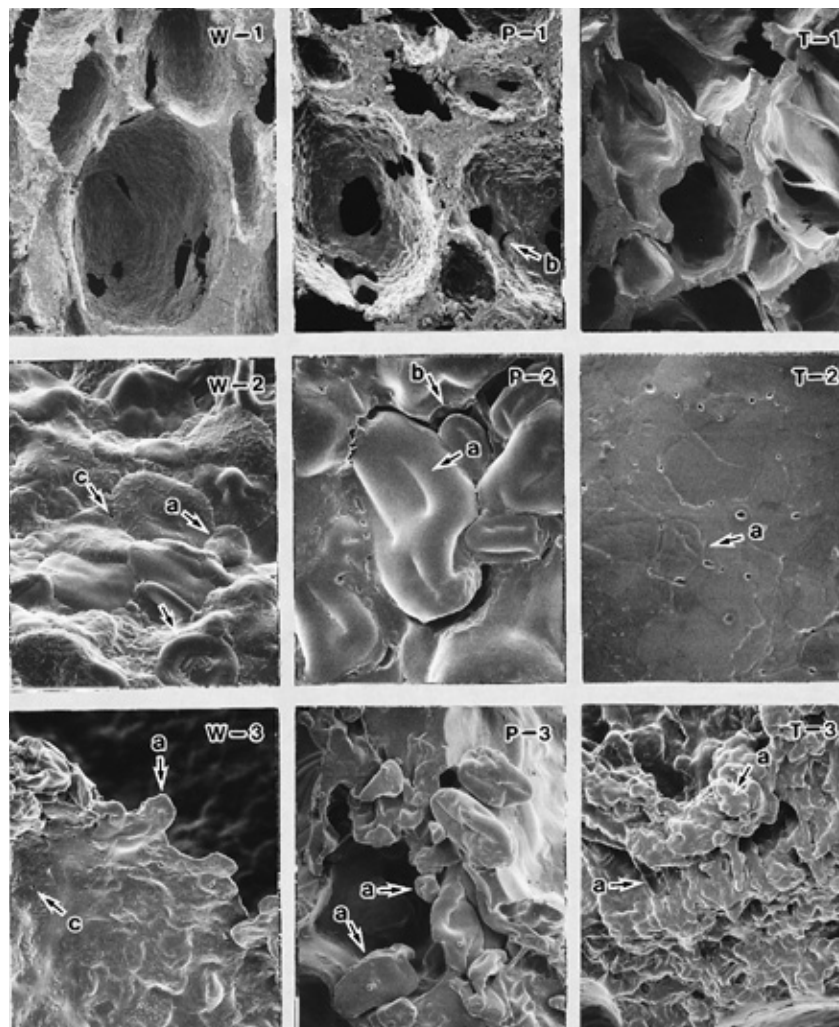


Fig. 6. Scanning electron microscopy of bread baked with reconstituted flour of vital gluten and wheat starch (W-1, W-2, W-3), potato starch (P-4, P-5, P-6), or tapioca starch (T-7, T-8, T-9). Arrows a, b, and c indicate starch granule, crack of gas cell wall, and small pore, respectively.

TABLE I
Loaf Volume, Specific Volume, and Oven Spring of Bread
from Wheat, Potato, and Tapioca Starches

	Loaf Volume (cm ³)	Specific Volume (cm ³ /g)	Oven Spring (mm)
Wheat starch bread	481 ± 22	3.55	29.2 ± 5.0
Potato starch bread	409 ± 20	3.00	17.6 ± 4.2
Tapioca starch bread	552 ± 29	4.11	40.0 ± 3.6

The results of this study, based on three starches with diverse gelatinization properties, generate two conclusions. First, the starch in bread doughs should gelatinize and set the dough after complete expansion. Earlier gelatinization (as in potato starch) produces a smaller loaf. Wheat starch, with its higher gelatinization temperature, allows a longer time for the loaf to expand, resulting in a larger loaf volume. Second, the starch granules should retain their integrity in a gluten matrix after gelatinization to provide cracks in the gas cell membranes after the dough is set in the oven. Tapioca starch produces an impermeable membrane (the starch granules fuse together forming a gas discontinuous system) which is extensible for a relatively longer time. This leads to a larger loaf that collapses during cooling after baking. Wheat starch granules gelatinize individually in the gluten matrix, which causes cracks in the cell membranes and thereby prevents shrinkage during cooling after baking.

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