Effect of Substitution of Waxy-Wheat Flour for Common Flour on Dough and Baking Properties

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The effect of substitution of waxy-wheat flour (WWF) for common wheat flour, ‘Hermes’ on dough and baking properties was determined. Flours consisting of 20% WWF and 80% Hermes (20 WWF) and 40% WWF and 60% Hermes (40 WWF) were used. Two other mixed flours were prepared for comparison: one consisted of 20% Chinese spring flour (CSF) and 80% Hermes (20 CSF) and the other of 40% CSF and 60% Hermes (40 CSF). Breadcrumbs became softer with increasing WWF substitution, and harder with increasing CSF substitution. From cross sections of these breads from 20 WWF and 40 WWF, the partial substitution of WWF for Hermes was considered favorable for baking results. Especially, 40 WWF made larger loaves and improved glutinous texture, such as the chewing property or adhesiveness of breadcrumbs, as compared with Hermes alone. DSC data showed that WWF retarded the staling of breadcrumbs during storage and also accelerated the refreshing of breadcrumbs with softness and glutinous texture after reheating. Substitution of WWF decreased the setback of viscosity under the holding temperature and suppressed the gelation of starch under cooling, both of which improved the pasting property of starch. In addition, WWF appeared to suppress the formation of an insoluble network structure of starch during cooling, which improved the tolerance of gelatinized starch to the retrogradation. These results indicate that the partial substitution of WWF for common flour improved the softness and glutinous texture of breadcrumbs and retardation of staleness. Consequently, WWF might have applications in practical baking.

Keywords: waxy-wheat flour, breadmaking, starch, dough, retrogradation

Rice is a staple food in Japan and two kinds of non-glutinous and glutinous rice have long been known. From the viewpoint of Japanese food habits, stickiness or glutinosity is needed to some extent for most kinds of foods. These days, various kinds of processed-foods are sold in Japan and most of them contain some quantity of wheat flour. Since wheat-containing-food, especially bread, is eaten almost every day, a glutinous texture might also be required for breads.

Wheat grains containing various ratios of amylase and amylopectin have recently been prepared by genetic recombination. Waxy (amylose-free) wheats have been produced in Japan (Nakamura et al., 1995, Kiribuchi-Otabe et al., 1997, Yasui et al., 1997) and several studies have examined their properties (Yamamori & Quynh, 2000; Araki et al., 2000; Araki et al., 1999; Fujita et al., 1998; Miura & Sugawara, 1996). In contrast, SGP-1, a starch granule protein was recognized to produce a novel starch (high-amylose starch) and is used to increase the number of varieties of wheat starch (Yamamori et al., 2000).

Although only a small amount of starch is exuded from starch granules during gelatinization of starch in breadmaking, gelation of amylase and crystallization of amylopectin have been reported to be responsible for the retrogradation of starch. In general, the staleness of breadcrumbs during storage is caused by amylopectin rather than amylase (Matsumoto, 1997b). Waxy cornstarch is believed to retard the retrogradation of starch with higher swelling power and viscosity of the paste, as compared with normal cornstarch (Taira, 1996). Since the staleness of bread is caused by the retrogradation of starch, the practical use of waxy-wheat flour (WWF) influences the properties of processed-foods during heating. Therefore, in this study, a portion of common wheat flour was replaced by WWF, and the effects of WWF on the dough and bread qualities were determined. We particularly focused on the effect of WWF on the retrogradation of starch. We also discuss the role of amylopectin in the retrogradation of starch and the staleness of bread.

Materials and Methods

Flour and chemicals

To identify the relationship between the amount of amylase and the baking properties, the normal amylase content and non-waxy wheat grain, Chinese Spring (CS) was used and test-milled by Okumoto Flour Milling Co., Ltd. (Osaka), and the wheat flour was called CSF. Waxy wheat grain was selected from the F2 progeny from CS (Kanto 107 7A)/CS (Kanto 107 4A)/CS (Bai Huo 7 D) and backcrossed twice to the normal CS (Miura et al., 1999). This line was confirmed to be nearly isogenic to CS with respect to agronomic performance and chain-length distribution in amylopectin structure (Miura et al., 2001). The waxy wheat grain was test-milled
by Okumoto Flour Milling Co., Ltd. and called WWF. A conventionally milled commercial hard-type wheat flour, ‘Hermes’ was donated by Okumoto Flour Milling Co., Ltd. to compare its quality with those of CSF or WWF-substituted flour samples. Other chemicals used were without further purification.

Bread making The breadmaking formula and procedures were carried out with a slightly modified AACC method (10-10B 1995). Fifty grams of flour, 0.75 g of sodium chloride, 3 g of sucrose, 1.00 g of dry baker’s yeast (Asahi Kasei Co., Ltd., Tokyo) and the appropriate amounts of water were mixed for 15 min using the automatic breadmaking apparatuses described previously (Morita et al., 1999). The optimum amount of water for each flour was determined from the water absorption ratio by farinograph mixing at 500 B.U. The mixed dough was subjected to the first fermentation for 90 min in a cabinet maintaining a constant temperature of 30˚C and relative humidity of 85%. Then during fermentation, one punching was performed after 60 min. Subsequently, the dough was divided into 3 pieces (15 g/piece), rounded and molded using a mechanical molder SM-230 (Baker’s Production Co., Ltd., Osaka), and placed in a baking pan. The dough was subjected to the final proof for 30 min in a cabinet maintaining a constant temperature of 30˚C and relative humidity of 90%. The sample was taken out, the loaf was weighed immediately, and the loaf volume was determined as follows. The flour slurry in water to substituted flours were calculated from values of water absorption of the flour samples, depending on the rate of substitution. After completion of the baking process, the bread was taken out, the loaf was weighed immediately, and the loaf volume was measured by the method of rapeseed displacement. The specific volume of bread after storage for various days was wrapped in aluminum foil and placed for 15 min in an oven of 110˚C. After standing for 1 h at room temperature, the compressing and chewing properties of breadcrumbs were measured using the apparatus and method described above.

Rheological test

Moisture content of breadcrumbs Moisture content of breadcrumbs after storage with or without heating was determined by the AACC method (44-15A 1994).

Measurement of firmness of breadcrumbs during storage Staleness of breadcrumbs, compression stress, failure strength and Young’s modulus were determined by the rheometer, as described previously (Morita et al., 1998). A 2×2×1 cm³ sample of breadcrumbs was used. The plunger had a 1-cm diameter, and the compression depth was controlled at 3 mm. Data were processed as described previously (Morita et al., 1998).

Glutinous texture of breadcrumbs To obtain the effect of WWF on the glutinous texture of breadcrumbs, adhesiveness and chewing property of heaved bread were measured by the modified refreshing method of Ghiasi et al. (1984). A slice of bread after storage for various days was wrapped in aluminum foil and placed for 15 min in an oven of 110˚C. After standing for 1 h at room temperature, the compressing and chewing properties of breadcrumbs were measured using the apparatus and method described above.

Differential scanning calorimetry (DSC) of breadcrumbs Apparent endothermic enthalpy which corresponds to the staling of breadcrumbs was determined by the same Shimadzu DSC (Model DSC-50, Tokyo) as reported previously (Morita et al., 1999). The DSC data were obtained using freeze-dried breadcrumbs, according to the method of Biliaderis et al. (1985). The heat of gelatinization (ΔH), initial temperature (T_i), peak temperature (T_p) and recovery temperature (T_r) were used to characterize the thermal transition of starch in breadcrumbs. Analyses were carried out in triplicate using 3 to 5 mg of sample and 2.5 times that amount of water. The samples were programmed at a rate of 10˚C/min from ap-proximately 25 to 120˚C.

Method of refreshing bread To determine the effect of reheating breadcrumbs after storage, the firmness, adhesiveness and chewing property of reheated bread were measured by the modified refreshing method of Ghiasi et al. (1984). A slice of bread after storage for various days was wrapped in aluminum foil and placed for 15 min in an oven of 110˚C. After standing for 1 h at room temperature, the compressing and chewing properties of breadcrumbs were measured using the apparatus and method described above.

Pasting test To obtain the pasting curve of various wheat flours, changes in the apparent viscosity of an aqueous wheat flour suspension were determined as follows. The flour slurry in a Brabender Viscograph was heated at a rate of 1.5˚C/min from 30 to 93˚C, held at the maximum temperature for 15 min, and then cooled at a rate of 1.5˚C/min to 40˚C. The sample was prepared using 65 g of wheat flour and 450 ml of distilled water by a slightly modified AACC method (20-10, 1994). The Brabender Viscograph was operated according to the procedure of manufacturing instrument in Brabender and AACC method (20-10, 1994).

Results and Discussion

Baking results To obtain additional information on flour quality of WWF, effects of CSF or WWF as a partial substitute for Hermes on specific loaf volume were tested (Fig. 1). The 20% (20 WWF) or 40 % (40 WWF) of WWF substitution for Hermes increased the specific loaf volume of bread, as compared with that of Hermes alone. In contrast, the substitution of CSF...
for *Hermes* with the same ratio of 20 (20 CSF) or 40 % (40 CSF) decreased specific loaf volume, as compared with those of 20WWF and 40WWF. To determine the effect of substitution of WWF on the staleness of bread crumbs was measured after 7 days of storage following baking (Fig. 2). Twenty and 40 WWF softened bread crumbs more than *Hermes*, and retarded their staleness during storage. The substitution of WWF in retarding bread staleness was more distinct than that of CSF. Furthermore, WWF softened the bread crumbs with the increasing ratio of substitution, whereas CSF hardened it with the increase.

**Softness of refreshed bread with CSF or WWF** To determine the effects of CSF or WWF on the refreshing of bread, the firmness of reheated bread crumbs after storage was measured (Fig. 3). Regardless of amylopectin content, amount of substitution or storage days, all kinds of bread crumbs were softened by reheating. The bread crumbs containing WWF could be softened and refreshed more distinctly by reheating than those with CSF. Therefore, the substitution of WWF for *Hermes* improved not only the softness, but also the refreshing of stale hard bread crumbs by heating, because of the high amylopectin content. Consequently, bread with WWF is expected to be useful for a daily diet and the bread quality is viewed as satisfying the diet of Japanese.

**Glutinous texture of breadcrumbs** To determine the effect of WWF substitution on the glutinous texture of bread crumbs, their adhesiveness and chewing properties were measured after storage. Immediately after baking, no distinct difference was observed in the adhesiveness between WWF and CSF (Fig. 4). However, 40% substitution of WWF for *Hermes* increased the adhesiveness of bread crumbs stored for up to 7 days, compared with that of *Hermes* alone. Forty WWF also increased the adhesiveness of reheated bread crumbs stored for this period more than other samples. Forty WWF showed the highest value of chewing property of all samples tested immediately after baking (Fig. 5), and after storage for 7 days this property was increased by reheating more than other samples. Therefore, the stickiness or glutinous properties of bread crumbs made from 40 WWF could be more easily recovered by reheating than other samples.

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**Fig. 2.** Effect of substitution of waxy-wheat flour on firmness of bread crumbs during storage. 20 CSF, CSF (20%)+*Hermes* (80%); 40 CSF, CSF (40%)+*Hermes* (60%); 20 WWF, WWF (20%)+*Hermes* (80%); 40 WWF, WWF (40%)+*Hermes* (60%).

**Fig. 3.** Effect of substitution of waxy-wheat flour on refreshing of bread crumbs by reheating. Abbreviations are the same as in Fig. 2.

**Fig. 4.** Effect of substitution of waxy-wheat flour on adhesiveness of bread crumbs. Abbreviations are the same as in Fig. 2, except that 7R is reheating after storage for 7 days.

**Fig. 5.** Effect of substitution of waxy-wheat flour on chewing property of bread crumbs. Abbreviations are the same as in Fig. 2, except that 7R is reheating after storage for 7 days.
Since these properties, which are required by Japanese people, were increased by WWF substitution for Hermes, WWF can be expected to practically improve breadmaking.

**Cross view of breadcrumbs** Figure 6 shows cross views of breadcrumbs with various wheat flours. When Hermes was partially substituted by CSF or WWF, the appearance of the bread seemed larger than with Hermes alone, as is obvious from Fig. 1. For bread baked with WWF, the color of crumbs and crust was more yellowish. Especially, bread baked from 40 WWF contained some gas cells extremely large in size. In general, large gas cells with a thin membrane and of constant size are considered to be favorable for bread quality (Matsumoto, 1997a), but 40 WWF also contained small gas cells too, so that the appearance was not more favorable than Hermes. Partial substitution of WWF for Hermes, however, may not greatly affect the size of gas cells. Therefore, the partial substitution of WWF was suggested for use in practical breadmaking.

**Moisture content of breadcrumbs** The moisture content of breadcrumbs was tested during 1–7 days of storage to determine the relationship between staling and the evaporation of water. Regardless of the ratio of substitution of WWF for Hermes, the moisture content was around 27.0–29.1% and the degree of water evaporation during storage did not change in any of the substituted breadcrumbs. When Hermes was partially substituted with CSF and WWF, breadcrumb moisture content seemed to be higher than with Hermes alone. This might be due to the higher water absorptions of CSF and WWF than that of Hermes. The high moisture content of breadcrumbs seemed to be associated with their softness, as shown in Figs. 2 and 3. The moisture content of the reheated loaf was essentially unchanged before and after treatment; the difference in moisture was less than 3.8%. After storage for 7 days, the firmness of breadcrumbs did not change with or without reheating, as reported previously (Ghiasi et al., 1984). In the present study, all substitutions with CSF or WWF resulted in similar moisture content in the crumbs, regardless of reheating. Therefore, these tendencies might be consistent with previous results, as described above.

**DSC results of breadcrumbs** DSC data of breadcrumbs stored for 5 days are shown in Table 1. The first endothermic peak was observed between 40–60°C, which is believed to be formed from aged amylopectin gel (Biliaderis et al., 1985). Forty WWF showed the smaller enthalpy than Hermes alone. The partial substitution of WWF was therefore suggested to suppress the crystallization of amylopectin, retarding the staling of breadcrumbs during storage. After a 5-day stored sample was reheated at 110°C, it was freeze-dried and analyzed by DSC. The enthalpic peak of a reheated and freeze-dried bread sample has been reported to be much smaller (Ghiasi et al., 1984) than that of a non-reheated sample. In the present study, the enthalpy of aged amylopectin for all tested samples after reheating at 110°C was decreased compared with values before reheating. The level of enthalpy was around 0.13–0.40 J/g and was very small. This result suggests that a portion of recrystallized amylopectin in retrograded starch was melted by the reheating at high temperature. Hermes decreased the enthalpy more obviously than other samples tested, and therefore was thought to contain more recrystallized amylopectin in the starch than other samples. In contrast, the second melting enthalpy which corresponds to the degradation of amylose-lipid complexes was increased by reheating. During baking, only approximately 1% of soluble amylose is leached from starch granules in bread as a soluble amylose by the swelling of starch (Matsumoto, 1997b). When stale bread was reheated, a portion of the remaining insoluble amylose in the starch granules might leach out from the starch, strengthening the interaction of amylose and lipids to form the amylose-lipid complexes again, resulting in increasing the second peak of amylose-lipid complexes. Hermes or 40 CSF with normal amylose content accelerated the formation of amylose-lipid complexes by reheating more than 40 WWF.

When wheat starch is cooled after gelatinization, the aged starch makes a gel only if amylose is first leached from starch granules. The part of soluble amylopectin from aged 50% pastes was similar to freshly prepared pastes at 50°C. However, aged amylose cannot be reversed by heating at 50°C. Retrogradation of starch has long been thought to play an important role in the
staling of bread. The endothermic enthalpy of retrogradation of amylopectin is given by DSC data, but retrogradation of amylose was not observed in the system, since the retrogradation of aged amylose was distinctly reversible above 100°C. It has been ambiguous whether retrogradation of starch can be defined only in terms of the amylopectin, or whether both amylose and amylopectin must be considered (Pomeranz, 1988c). Twenty and 40 WWF decreased the firmness of breadcrumbs more than Hermes after reheating as shown in Fig. 3. However, from DSC data, there were no distinct differences in the amount of crystallized amylopectin among all samples. Normally, for the staleness of starch-containing-foods such as cooked rice or bread, crystallization of retrograded starch is too little to recognize. Moreover, since bread contains not only starch but also protein or lipid, the firmness of stale breadcrumbs might be caused by both denaturation of gluten and retrogradation of starch. These results suggest that WWF retarded the staleness of breadcrumbs during storage and accelerated their refreshing after reheating.

Pasting results of various wheat flours

Table 2 shows changes in the apparent viscosity of an aqueous wheat flour suspension using a Viscoagraph. On the Viscoagraph curve, the increase in viscosity is due to the release of exudates from granules rather than to the swelling of granules. Starch is a semicrystalline polymer and should have the characteristics of both a crystalline and an amorphous polymer. The crystalline regions in a starch granule, primarily amylopectin, are thought to be dispersed in a continuous amorphous matrix (Pomeranz, 1988b). The gelatinization of starch is associated with the following two phenomena: loss of crystalline structure and swelling of starch granules. The fast process was regarded as corresponding to the melting of crystallites, and the slow process to the disentangling of chains (Pomeranz, 1988a).

Hermes showed the highest viscosity among all tested samples. Normally waxy cornstarch makes a transparent paste with a high viscosity during gelatinization. Moreover, the paste solution does not gel and is highly tolerant of the retrogradation of starch. WWF made the paste faster with a higher viscosity than CSF (data not shown). However, in the present study, regardless of the kind of wheat flour, when Hermes was substituted for CSF or WWF, the peak, breakdown or final viscosities were decreased as compared with Hermes alone. Moreover, 20 and 40 WWF showed another peak around 66.8–67.1°C, which was caused by WWF alone, and its viscosity was in the range 72–140 BU. This curve indicated that characteristics of starch in WWF were quite different from those in Hermes of common wheat flour. The first peak increased with increase in the ratio of substitution; substitution of CSF slightly increased the initial and peak temperatures over Hermes alone, while the substitution of WWF slightly decreased the temperatures, resulting in a faster paste formation than Hermes alone. Moreover, substitution of CSF or WWF (especially 40 WWF) resulted in lower values of breakdown, setback and total setback compared with the values with Hermes alone. Therefore, substitution of WWF maintained a high viscosity under the holding temperature, and suppressed the gelation of starch during cooling, both of which improved the gelatinization of starch. WWF might also restrain the formation of an insoluble network structure of starch during cooling, improving the tolerance to retrogradation of starch caused by the high amylopectin content. Commercial breads with a waxy-taste, such as glutinous or sticky textures, are recently selling well, despite their higher price, indicating these textures are becoming popular with our consumers. These results indicate that the partial substitution of WWF for common wheat flour improves the softness and glutinous texture of breadcrumbs and retards staleness, and thus making it applicable for practical baking.

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References


<table>
<thead>
<tr>
<th>Sample</th>
<th>$T_p$ (˚C)</th>
<th>$T_T$ (˚C)</th>
<th>$V_p$ (B.U.)</th>
<th>$V_T$ (B.U.)</th>
<th>$V_{BD}$ (B.U.)</th>
<th>$V_{SB}$ (B.U.)</th>
<th>TSB (B.U.)</th>
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<tr>
<td>Hermes</td>
<td>63.0</td>
<td>92.3</td>
<td>570</td>
<td>420</td>
<td>1280</td>
<td>150</td>
<td>710</td>
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<tr>
<td>20 CSF</td>
<td>63.8</td>
<td>92.3</td>
<td>513</td>
<td>425</td>
<td>1340</td>
<td>88</td>
<td>828</td>
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<tr>
<td>40 CSF</td>
<td>63.8</td>
<td>92.6</td>
<td>483</td>
<td>410</td>
<td>1258</td>
<td>25</td>
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<td>348</td>
<td>280</td>
<td>690</td>
<td>68</td>
<td>343</td>
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<tr>
<td>40 WWF</td>
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<td>205</td>
<td>178</td>
<td>403</td>
<td>28</td>
<td>198</td>
</tr>
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$T_p$, Initial temperature; $T_T$, Peak viscosity temperature; $V_p$, Peak viscosity; $V_{BD}$, Breakdown viscosity; $V_T$, Final viscosity; BD, Breakdown, SB, Setback; TSB, Total setback. B.U. is Brabender Unit. Abbreviations are the same as in Fig. 1.


