J. Food Sci. Nutr.
Vol. 4, No. 1, p. 6~13 (1999)

Development of Buckwheat Bread:
3. Effects of the Thermal Process of Dough Making on Baking Properties

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Abstract

The quality of the buckwheat bread made with previously heated (55°C) and cooled buckwheat flour dough with the addition of ascorbic acid (AA) or/and sodium stearoyl lactylate (SSL) was evaluated. With heat treatment, handling property of dough and grain of the bread crumb were markedly improved and stickiness of the dough decreased. The optimum resting time to produce the best loaf volume and grain was found to be 3hr for both unheated and heated doughs. Heat treated dough showed higher dough expansion rate during fermentation than unheated dough, even though heated dough had lower loaf volume, probably because of an improper oven spring. Increase in shortening of dough formula from 3% to 5% improved loaf volume without improvement of handling property. With the addition of 100 ppm AA or/and 0.5% SSL, loaf volume and crumb grain were improved for both unheated and heated doughs. Microscopic analysis of a mixed dough by scanning electron microscope (SEM) showed that heated dough had a continuous network whereas unheated dough was discontinuous. The addition of AA and SSL gave the dough a more continuous structure with strengthened strands or interactions between the starch granule and protein. Therefore, it appears that the presence of continuity in heated buckwheat bread dough is related to the improved loaf volume and crumb grain without dough stickiness.

Key words: buckwheat bread quality, heat treatment, dough stickiness, SEM

INTRODUCTION

Wheat dominates breadmaking all over the word. However, demand for whole wheat bread and other types of bread made from cereals other than wheat, increased considerably in the last few years because of the better nutritional image and an increasing preference for their organoleptic characteristics (1). Usually such breads are made from wheat flour mixed with flours from other cereals. It is desired to promote the utilization of nonwheat cereals among the larger segment of populations and to improve the protein content in these products. Wheat flour is unique among cereal flours. It can form a strong visco-elastic dough that retains gas produced during fermentation and the early stages of baking resulting in light-textured products (2). Wheat gluten proteins are believed to be primarily responsible for the uniqueness of wheat flour dough (3).

Generally, the ability of cereal flours other than wheat to retain gas was known to be low because of a lack of gluten proteins. Negative effects of nonwheat cereal flours on dough handling and the quality of finished products were reported, suggesting that rheological properties are significant in breadmaking. Problems that have been reported include excessive dough stickiness, low dough mixing tolerance, and reduced bread volume (4-9). Although rye flour is second only to wheat flour in its ability to retain gas, the extent of gas retention is limited. Pure rye dough tends to be sticky, and the breads are very compact. Therefore, rye flours are usually blended with various amounts of wheat flour for bread production in Canada and the United States (10). To overcome the volume-depressing effect of nonwheat cereals on breadmaking, various gums and surfactants have been used successfully in breads made with wheat starch and other cereal flours and starches (7,11-13).

The dough stickiness problem is of particular concern to large mechanized bakeries where it can result in costly disruptions to production schedules and in loss of product quality. Rheological properties of the materials depend on their structure and on the arrangement of the constituents and the forces acting between them. The rheological properties of a wheat flour dough system are analogus to the properties of gluten. Specific non-protein components of flour interact with specific proteins of gluten and contribute significantly to their rheological properties (14).

The rheological properties of most materials are highly sensitive to temperature (15). Heating causes changes in the functionality of foods (16). Such changes may be closely associated with alterations in the chemical form of the major constituents present. Dough is no exception. Ambient temperature frequency scans of heated and cooled flour-water doughs showed that irreversible rheological changes were caused by heating dough to 55~75°C when a dynamic rheometer was used (17). Starch gelatinization, gluten cross-linking, or both are possible explanations for the thermally induced rheological change.

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Buckwheat flour exhibits relatively low cohesion, therefoce resulting in sticky weak dough. However, a marked rise in the hardness, cohesiveness and springiness of the buckwheat dough was found on heating (18). The objective of the present study was to demonstrate and document the quality of buckwheat bread made with previously heated and cooled buckwheat flour dough and the possible usefulness of heat treatments in buckwheat flour bread making and dough additives such as surfactant and ascorbic acid on dough expansion rate during *fermentation, handling property and loaf volume.*

MATERIALS AND METHODS

Materials

Wheat flour was a commercially-milled strong bread flour provided by Shinhan Flour Mill, Co. Milled buckwheat flour was obtained at the Bongpyung Agricultural Co-Operative. The buckwheat flour was stored in a freezer until use. Ascorbic acid (AA) was a product of Sigma. Sodium stearoyl lactylate (SSL) was provided by Pals Gaard, Co. Table 1 shows the dough ingredients as weight parts of flour.

Breadmaking

Strong wheat flour (70%) and buckwheat flour (30%) were used for making bread. The straight-dough bake test procedure in the standard AACC methods (19) was followed to produce bread. Part of the formula water was added to the buckwheat flour and mixed. Heat treatment of buckwheat dough was heated in a 55℃ water bath (Jeio Tech Co., Model No : WB-30D). Heat treated buckwheat dough was rested at refrigeration temperature for 1, 2, 3, 4 and 24 hr. Unheated buckwheat dough was rested at room temperature for 0, 1, 2, 3, 4 and 24 hr. Buckwheat dough and ingredients were mixed to optimum in a mixer (Hobart Model : H-3841, USA). Temperature of the dough from the mixer was controlled at 27±1℃. The dough was fermented in a proof cabinet (Dae-Yung Machinery Co., Korea) at 30℃ and 75% RH for 60 min. After fermentation, it was divided into loaf-sized pieces, rounded, molded into a loaf shape, and placed into a baking pan. The dough then underwent an additional fermentation (proofing) to reach 1 cm above the pan. After reaching the desired size, it was placed in the oven (Hobart Model : HEC-404, USA) and baked. After baking, loaves were cooled, and then loaf volume was estimated by the displacement of millet seeds. A summary of a straight dough baking procedure is shown in Fig. 1.

Table 1. Ingredients of dough

Ingredients	Ratios (%)
Wheat	70
Buckwheat	30
Yeast	1.3
Sucrose	6
Salt	2
NFDM[1)]	3
Shortening	3
SSL[2)]	0.5
AA[3)]	0.01 (100 ppm)
Water	Variable

[1)]NFDM (non-fat dry milk)
[2)]SSL (sodium stearyl lactylate)
[3)]AA (ascorbic acid)

Dough stickiness measurement

Dough stickiness for each sample was measured with an objective method (20) and compared with subjective evaluation (handling property) taken at dough mixing. A Texture Analyser (model TA-XT2, Stable Micro Systems, England) was used in this study to provide a constant compression force and to measure the tension force. The TA-XT2 library program No. 3 (adhesives test) was used. The compression force selected was 40 g-force. The diameter of the plexiglass probe was 25 mm. The trigger force was set at 5 g-force. The compression travel speed for the probe was 2.0 mm/s. The probe reversing speed was 10.0 mm/s, which is the maximum reversing speed of the texture analyser. The holding time was 0.1 sec. The probe travel distance was selected as 10.0 mm.

Weigh ingredients
↓
Mix buckwheat flour with water
↓
Heat treatment (55℃)   No heat treatment
↓
Resting
↓
Mix dry ingredients (except H_2O and shortening)
↓
Add buckwheat flour dough
↓
Add rest of water
↓
Mix (3 min at speed 1, 2 min at speed 2)
↓
Add shortening
↓
Mix (2 min at speed 1, 6~7 min at speed 2)
↓
Determine dough temperature (27±1℃)
↓
Put dough into fermentation cabinet (30℃, 75%) for 1hr
↓
Punch
↓
Scale dough into pieces (126g per piece)
↓
Round dough piece and rest for 10 min
↓
Mold
↓
Pan
↓
Proof of height (1 cm above pan)
↓
Bake at 180℃ for 15 min

Fig. 1. Flow chart of straight dough baking procedure.

Scoring dough handling properties

Dough handling properties were scored using a five-point scale (21). The scoring criteria were as follows: 5, good dough-handling properties(as good as white flour dough): 4, dough can be handled without difficulty when hands are lightly greased: 3, dough can be handled with slight difficulty when hands are greased: 2, dough can be handled with slight difficulty when hands are greased and slight amount of dusting flour is applied: and 1, dough is difficult to handle even when hands are greased and dusting flour is applied.

Dough expansion rate

The increasing height of the dough in the mass cylinder was measured every 10 min during fermentation. The volume of expansion was obtained from the height increment of the dough.

Crumb structure by visual observation on a scale

Crumb structure of one-day-old bread was rated by visual observation on a scale of satisfactory (S), questionable to satisfactory (Q-S), questionable (Q), questionable to unsatisfactory (Q-U), and unsatisfactory (U) by Park et al. method (22). The highest score of satisfactory was for crumb with small holes and thin cell walls, whereas the lowest score of unsatisfactory was for crumbs with large holes and thick cell walls.

Scanning electron microscopy (SEM)

Observation of the microstructure of dough was done on a Hitachi scanning electron microscope (Model : S-2400). Samples were prepared as follows. After mixing, bread dough was frozen by liquid nitrogen. The frozen dough was cracked and freeze dried in a freeze dryer (Il SIN Engineering Co., Korea). The mounted sample was coated with a thin layer of gold, and viewed at 20-22KV and magnifications of 500 and 1500.

Statistical analysis

All experiments were repeated at least three times. Statistical analyses were performed by using the SPSS (Statistical Package for Social Science). Means were compared by the least significant difference (LSD) test at α=0.05.

RESULTS AND DISCUSSION

Determination of optimum absorption

Absorption was the amount of water required to bring the dough to proper viscoelasticity. The best loaf volumes were obtained with the 64~65% water level which did not produce an excessively sticky or bucky dough. The consistency was tested subjectively and objectively by an experienced operator. Differences in absorption between the heated and unheated dough might be attributed to the swelling of starch granules in the buckwheat flour.

Effects of heat treatment and resting time

In general, hot water (70~90°C) had been used for buckwheat noodle-making with mixed flours of buckwheat (10~50%) and wheat flour or corn starch because it is difficult to shape the noodle due to the lack of viscoelasticity in buckwheat flour using room temperature water (23). Undoubtedly, rheological characteristics were also considered to play an important role in the palatability, acceptability and machinability of buckwheat bread (24). Hot water was used to attempt to improve the handling property of buckwheat bread dough. It was found that loaf volume did not change as the dough was heated up to 55°C and the volume decreased at 65°C (data not shown). Thus, 55°C was chosen to be suitable heating temperature of the dough for the following studies. Similar results were also obtained with buckwheat noodles made from buckwheat flour dough heated at 55°C, which resulted in acceptable hardness (18). Thermal processing around 55°C may be closely associated with the rheology of the buckwheat flour dough.

As shown in Table 2, handling property and grain of the bread crumb were improved markedly and stickiness of the dough also decreased with heat treatment. Eventually, the dough appears to become more cohesive and extensible. However, there was a depressing effect on loaf volume. Optimum mixing time required for fully developed dough changed slightly. Previous work with gluten-starch doughs (17) was reported that rheological changes occuring as the dough was heated from 55 to 75°C were the result of changes in the starch fraction, presumably because of starch gelatinization. Heating a gluten-water dough to 80°C increased the gluten's mixing time, still being cohesive and extensible. One possibility is that the changes in the surface of the starch granules induced by heat treatment affect the gluten proteins' ability to interact with each other to make random mixtures of protein fibrils with adhering starch granules in such a way that mixing requires much more mechanical work.

Handling property of heat-treated buckwheat flour dough was still not as good as white wheat flour dough's handling property although it was much better than that of unheated dough. During the resting time, the rheological properties of buckwheat dough could be changed (25). The bread properties for different doughs with different resting times are shown in Table 2. Loaf volume and handling proprety improved with resting, but the values of stickiness were not affected. The best loaf volume was obtained with the 3 hr resting for the unheated dough. As resting time increased, heated dough showed a small increase in loaf volume, whereas handling property was as good as white wheat flour dough. Improvement of the bread quality could be explained as follows. The increase in loaf volume with resting could be related to the the formation of new cross-links in the nonequilibrium entangled network during resting (25). Improved dough handling property could be also explained by the fact that during the development stage in dough mixing, the long molecules are stretched to an extended configuration, whose extended molecules tend to retract and viscosity was increased during resting. One might also speculate that bran in buckwheat flour could absorb more

Table 2. Effect of resting time of bread dough in part on bread property

	Resting time (hr)	Mixing time (min)	Water absorption[1)] (%)	Volume (cc)	Grain scoring[2)]	Stickiness (g)	Handling[3)] property
No heat treatment	0	13	64	330.0^{a}	3	0.430	2
	1	13	64	354.2^{b}	3	0.415	2.5
	2	13	64	364.2^{bc}	3	0.401	3
	3	13	64	373.3^{c}	3	0.425	3
	4	13	64	360.0^{b}	3	0.402	3
	24	13	64	367.5^{bc}	2.5	0.472	1.5
Heat treatment	1	14	65	343.3^{ab}	4	0.351	4
	2	14	65	336.7^{a}	4	0.375	5
	3	14	65	362.5^{b}	4	0.365	5
	4	14	65	355.0^{ab}	3.5	0.378	4.5
	24	14	65	356.7^{b}	4	0.375	4

[1)]Based on the weight of flour.
[2)]Crumb structure of one-day-old bread by visual observation on a scale: 1, satisfactory (S); 2, questionable to satisfactory (Q-S); 3, questionable (Q); 4, questionable to unsatisfactory (Q-U); 5, unsatisfactory (U). The highest score of satisfactory was for crumb with small holes and thin cell walls, whereas the lowest score of unsatisfactory was for crumb with large holes and thick cell walls.
[3)]Scoring dough handling properties; 5, good dough-handling properties (as good as white flour dough); 4, dough can be handled without difficulty when hands are lightly greased; 3, dough can be handled with slight difficulty when hands are greased; 2, dough can be handled slight difficulty when hands are greased and slight amount of dusting flour is applied; and 1, dough is difficult to handle even when hands are greased and dusting flour is applied.
[a-c]Means of six replicates in which the same superscripts in each column are not significantly different ($p<0.05$).

free water during the resting time, improving the handling property. When bran was added to bread dough, presoaking the ground bran improved loaf volumes because the rate of water uptake by the bran was relatively slow (26). The other possibility is that endogenous lipoxygenase in bran of buckwheat flour functions, improving the rheological properties of dough, presumably by oxidizing protein sulfhydryl groups (26-29).

No further increase was observed in loaf volume, grain and handling property when the dough rested for more than 3 hrs. During the 4, 24 hrs resting, the loaf volume did not further increase and handling properties of the dough become rather poor. This detrimental effect may be accentuated by the presence of undesirable enzymes or constituents that interact strongly with gluten proteins and thereby inhibit development of desirable rheological properties in the buckwheat flour.

The optimum resting time to produce the best loaf volume and grain was found to be 3 hr for both unheated and heated doughs.

Effect of shortening, SSL, and ascorbic acid (AA)

To improve the bread quality further, various levels (3, 5, 7%) of shortening, 0.5% SSL and 100 ppm AA were added to the dough formula. Increase in shortening of dough formula improved loaf volume (Table 3). Its effect on the loaf volume was expecially greater for 7% shortening added whereas handling properties become sticky and less desirable as the amount of shortening increase. Optimum level of shortening was found to be 5%, concerning acceptable loaf volume, crumb grain and rheological properties of doughs. Thus, the major effect of adding shortening to bread dough is an increase in the volume of the bread.

When dough from moderately matured flour is treated with appropriate levels of oxidants, they become more elastic and resistant to extension and less sticky and more lively than untreated dough (30). Ascorbic acid has been used as an oxidizing flour improver which is believed to have beneficial effects due to the oxidation of cysteine residues in gluten proteins to form disulfide bridges which cross-link and strengthen the protein (31). The resulting change in protein structure is hypothesized to account for the changes in dough properties (e.g., improved gas retention) and the improvement in the quality of baked loaf (32). With the addition of 100 ppm AA or 0.5% surfactant, SSL, loaf volume and crumb grain were improved for both unheated and heated doughs (Table 4). It has been found that oxidants and heat treatment both cause the number

Table 3. Effect of shortening on bread property

	Shortening (%)	Mixing time (min)	Water absorption (%)	Volume (cc)	Grain scoring	Stickiness (g)	Handling property
No heat treatment	3	13	64	358.3^{a}	2.5	0.404	3
	5	13	64	386.7^{b}	3	0.402	3
	7	13	64	384.2^{b}	2.5	0.411	2
Heat treatment	3	14	65	351.7^{a}	4	0.337^{a}	5
	5	14	65	371.7^{b}	4	0.356^{a}	4.5
	7	14	65	381.7^{b}	3.5	0.392^{b}	3

[a,b]Means of six replicates in which the same superscripts in each column are not significantly different ($p<0.05$)

Table 4. Effect of oxidant and emulsifier on bread property

	Shortening (%)	Additive[1)]	Mixing time (min)	Water absorption (%)	Volume (cc)	Grain scoring	Stickiness (g)	Handling property
No heat treatment	3	Control	13	64	358.3^{a}	2.5	0.404^{b}	3
		AA	14	64	372.5^{b}	3.5	0.346^{a}	3
		SSL	14	64	375.8^{b}	4	0.300^{a}	3
		AA+SSL	14	64	381.7^{b}	4	0.322^{a}	3
	5	AA+SSL	14	64	400.0^{c}	4	0.358^{ab}	3
Heat treatment	3	Control	14	65	351.7^{a}	4	0.337	5
		AA	15	65	359.2^{ab}	4.5	0.350	5
		SSL	15	65	365.0^{ab}	5	0.336	5
		AA+SSL	15	65	369.2^{b}	4.5	0.354	5
	5	AA+SSL	15	65	395.0^{c}	4.5	0.344	5

[1)]Control=non additive, AA=ascorbic acid, SSL=sodium stearoyl lactylate

[a-c]Means of six replicates in which the same superscripts in each column are not significantly different ($p<0.05$).

of cross-links to increase (33). According to Krog (34), surfactant can function as dough conditioners in two ways. First, surfactant molecules may interact with gluten proteins by means of their hydrophobic and/or hydrophilic groups. Second, surfactants can interact in bulk form with the dough's water phase, forming lamellar type lipid-water structures. Bimolecular lipid layers can associate with both polar and nonpolar surfaces of protein aggregates or stabilize air-water interfaces. Synergistic effects on loaf volume appeared when SSL and ascorbic acid were used simultaneously. Maximum loaf volumes of 400 cc and 395 cc were obtained with the addition of 5% shortening, 100 ppm AA and 0.5% SSL for the unheated and heated dough, respectively. The mixing time increased and stickiness decreased, improving the handling property of the dough, with the addition of SSL and AA. Therefore, the use of additives, AA and SSL, and the increase of shortening level up to 5% could overcome the reduced loaf volume of bread made from heated dough of which handling properties were still superior to those of unheated doughs. The resultant bread also possesses a cell structure with uniformly small, thin walled cells and a soft texture. Thus, handling properties of buckwheat bread dough and the bread quality were acceptable with 5% shortening, 100 ppm AA and 0.5% SSL.

Dough expansion

Optimum fermentation represents that point at which the effects of interacting factors such as the character of flour, yeast level, temperature, formula ingredients, degree of oxidation, etc., are in balance (30). When the correctly mixed dough is fermented, two sets of forces come into play: gas production and gas retention. Gas production primarily involves the biological functioning of yeast on available fermentable carbohydrates, whereas gas retention is largely a measure of mechanical and physicochemical modifications of the colloidal structure of the dough during mixing and during the course of fermentation. It was hypothesized that gas retention is corresponds to dough expansion (35).

The effects of heat treatment, shortening, SSL, and AA (oxidant) on the physical properties of dough can be detected in the expansion of dough in a mass cylinder as shown in Fig 2, 3, and 4. Heat treated dough showed higher dough expansion rate during fermentation than unheated dough, even though heat treated dough had lower loaf volume, probably because of an improper oven spring. Increase of the amount of shortening did not increase dough expansion, but the addition of SSL and AA did. However, loaf volume of resulting bread increased as the level of shortening increased, possibly due

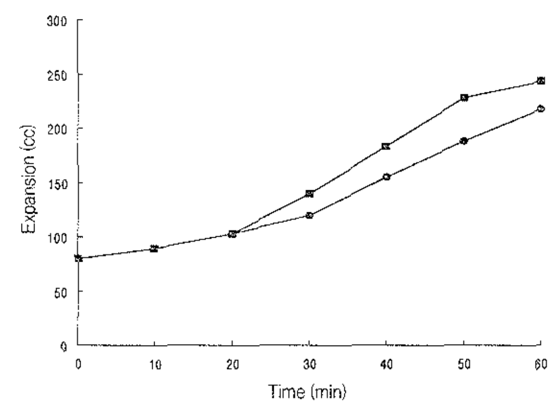

Fig. 2. Effect of heat treatment on dough expansion during fermentation. ●: No heat treatment, ■: Heat treatment

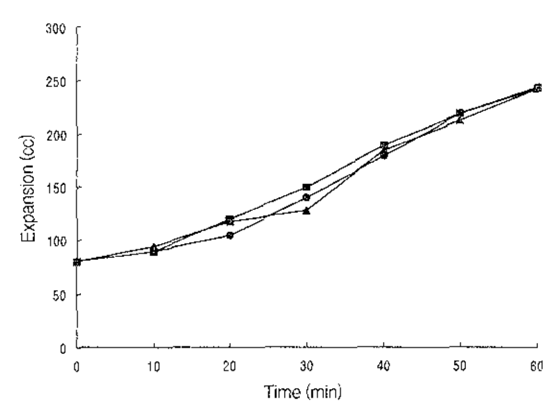

Fig. 3. Effect of shortening level on dough expansion during fermentation upon heat treatment. ●: 3%, ■: 5%, ▲: 7%

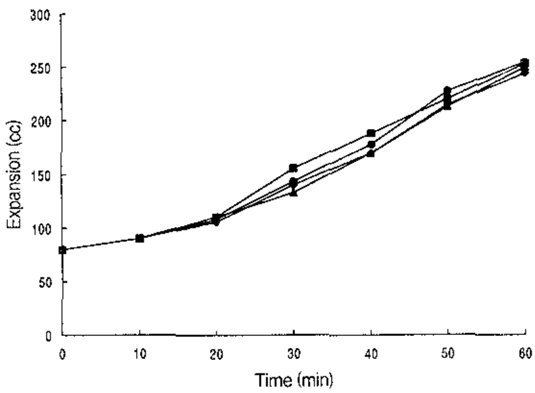

Fig. 4. Effect of additives on dough expansion during fermentation upon heat treatment. ●: SSL, ■: AA, ▲: SSL+AA, ◆: Control

to good expansion in the early stages of baking. These results may be interpreted in terms of the effect of shortening on oven spring as reported by some workers. Elton and Fisher (36) postulated that doughs made with and without shortening typically proof to the same height but differ greatly in final volume. Doughs made with shortening have shown to continue to expand for a longer time (to a higher temperature) during baking, thus attaining a larger volume than doughs made without shortening (36,37). They suggested three possible mechanisms for the shortening effect on increased time of loaf expansion and resultant increased volume. First, addition of shortening may alter dough permeability to water vapor and/or carbon dioxide. Second, shortening may delay the increase in apparent viscosity of the dough during starch gelatinization. Third, shortening may delay irreversible changes such as protein denaturation. Probably, SSL and ascorbic acids may form strong bonds with the flour proteins or surface of starch granules in the dough development stage, resulting in dough having viscous flow properties and, therefore, allowing the gas bubbles to expand. The total volume of the dough mass is increased or in other words, the dough is leavened. Understanding the structure of the dough system needs to be challenged.

Scanning electron microscopy (SEM)

Microscopic analysis of a mixed dough, carried out in a scanning electron microscope, showed that unheated dough has relatively discrete particles with discontinuous structure, whereas those of heated doughs are not free (Fig. 5). Instead, heated dough has a continuous network with little organization. Visually, the size of swollen starch granules in heated dough does not appear to be different from those of unheated dough. Neverthless, heating may cause starch granule flexibility (fragile), which renders it susceptable to breakage. By mixing and thus more random mixture of protein fibrils with remnants of swollen starch granule become close to the structure of 100% wheat flour dough. Microstructure of heated dough with the addition of 100 ppm AA and 0.5% SSL shows clearly increased networking. The possibility may exist that the addition of AA and SSL gives the dough more continuous structure with strengthened strands or interactions between the starch granule and protein. AA probably altered the properties of the dough. Oxidation of the formation of SS cross-linkage is likely (33). It appears that the presence of continuities in dough is related to the improved handling property and increased strand network with strong dough resulting in improved loaf volume and crumb grain.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the financial support of the Korea Research Foundation made in the program year of 1997.

REFERENCES

1. Lai, C. S., Davis, A. B. and Hoseney, R. C. : Production of whole wheat bread with good loaf volume. *Cereal Chem.*, **66**, 224 (1989)
2. He, H. and Hoseney, R. C. : Gas retention of different cereal flours. *Cereal Chem.*, **68**, 334 (1991)
3. Finney, K. F. and Barmore, M. A. : Loaf volume and protein content of hard winter and spring wheats. *Cereal Chem.*, **25**, 291 (1948)
4. Martin, D. J. and Stewart, B. G. : Dough mixing properties of a wheat-rye derived cultivar. *Euphytica*, **35**, 225 (1986)
5. Chung, J. Y., Kim, C. S. and Kim, H. I. : Breadmaking properties of composite flours of wheat and buckwheat with different proportions. *J. Human Ecology, Changwon National University*, **1**, 113 (1997)
6. Graybosch, R. A., Peterson, C. J., Hansen, L. E., Worrall, D., Shelton, D. R. and Lukszewski, A. : Comparative flour quality and protein characteristics of 1BL/1RS wheat-rye translocation lines. *J. Cereal Sci.*, **17**, 19 (1993)
7. Chung, J. Y. and Kim, C. S. : Developments of buckwheat bread: 2. Effect of vital wheat gluten and water-soluble gums on baking and sensory properties. *Korean J. Soc. Food Sci.*, **14**, 168 (1998)
8. Borghi, B., Castagna, R., Corbellini, M., Heun, M. and Salamini, F. : Breadmaking quality of einkorn wheat. *Cereal Chem.*, **73**, 208 (1996)
9. Eliasson, A. C., Jernold, E. and Larsson, K. : Development of a gluten-free bread (in Swedish). *Livsmeldlsteknilk*, **27**, 150 (1985)
10. Drew, E. and Seibel, W. M. : Bread-baking and other uses around the world. In "*rye: Production, Chemistry, and Technology*" Bushuk, W. (ed.), Am. Assoc. Cereal Chem., St. Paul, MN., p. 127 (1976)
11. Kulp, K., Hepburn, N. and Lehmann, T. A. : Preparation of bread without gluten. *Baker's Dig.*, **43**, 34 (1974)
12. Mettler, E. and Seibel, W. : Optimizing of bread recipes containing mono-diglyceride, guar gum, and carboxymethylcellulose using a maturograph and an over rise recorder. *Cereal Chem.*, **72**, 109 (1995)
13. Nishita, K., Roberts, R. L. and Bean, M. M. : Development of a yeast-leavened rice-bread formula. *Cereal Chem.*, **53**, 626 (1976)
14. Mani, K., Eliasson, A. C., Lindahl, L. and Tragardh, C. : Rheological properties and breadmaking quality of wheat flour doughs made with different dough mixers. *Cereal Chem.*, **69**, 222 (1992)
15. Brocksma, H. A. and Bushuk, W. : Rheology and chemistry of dough. In *Wheat chemistry and technology*" AACC, St. Paul, MN., Vol. II, p. 131 (1988)
16. Cherry, J. P. : *Protein functionality in foods* (ACS Sympoium Series 147). Am. Chem. Soc., Washington DC. (1981)
17. Dreese, P. C., Faubion, J. M. and Hoseney, R. C. : Dynamic rheological properties of flour, gluten, and gluten-starch doughs. 1. Temperature-dependent changes during heating. *Cereal Chem.*, **65**, 348 (1988)

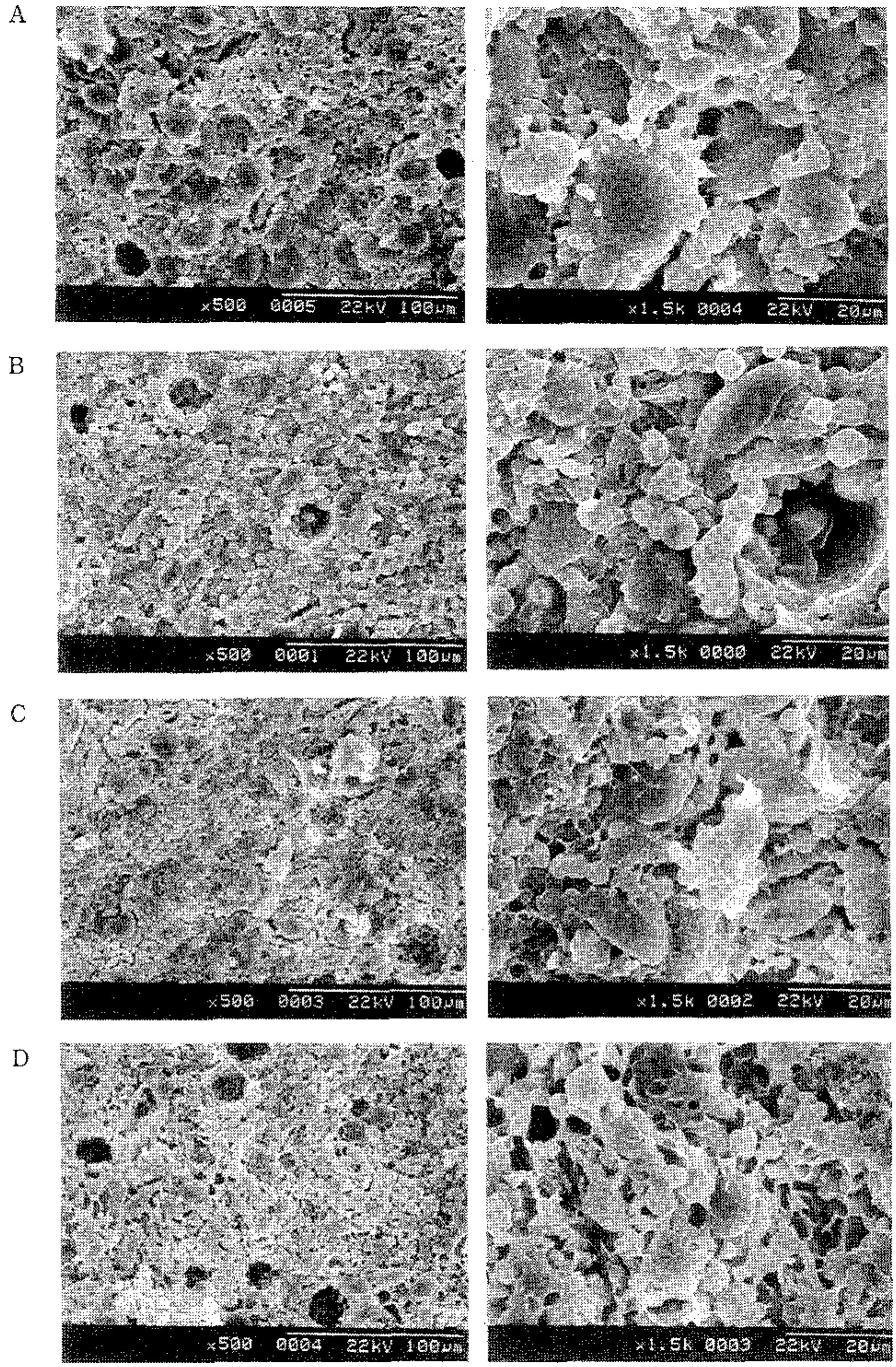

Fig. 5. Scanning electron micrographs of 100% wheat flour bread dough (A) and composite flour bread dough containing 30% buckwheat and 70% wheat flour. (B) unheated ; (C) heated ; (D) heated dough with the addition of 100 ppm ascorbic acid and 0.5% SSL.

18. Ikeda, K., Sakaguchi, T., Kusano, T. and Nishimura, A. : Changes in the functional properties of buckwheat protein on heating. *Fagopyrum*, **11**, 11 (1990)
19. AACC : *Approved methods of the AACC.* 8th ed., American Association of Cereal Chemists. St. Paul, MN., Methods 10-09 (1983)
20. Chen, W. Z. and Hoseney, R. C. : Development of an objective method for dough stickiness. *Lebensm-Wiss. U.-Technol.*, **28**, 467 (1995)
21. Lai, C. S., Davis, A. B. and Hoseney, R. C. : Production of whole wheat bread with good loaf volume. *Cereal Chem.*, **66**, 224 (1989)
22. Park, H., Seib, P. A. and Chung, O. K. : Fortifying bread with a mixture of wheat fiber and psyllium husk fiber plus three antioxidants. *Cereal Chem.*, **74**, 207 (1997)
23. Kim, Y. S. and Kim, H. S. : Dried noodle making of composite flours utilizing buckwheat and wheat flour. *Korean J. Nutr.*, **16**, 146 (1983)
24. Chung, J. Y. and Kim, C. S. : Development of buckwheat bread: 1. Effect of vital wheat gluten and water-soluble gums on dough rheological properties. Korean *J. Soc. Food Sci.*, **14**, 140 (1998)

25. Lindborg, K. M., Tragardh, C., Eliasson, A-C. and Dejmek, P. : Time-resolved shear viscosity of wheat flour doughs-effect of mixing, shear arte, and resting on the viscosity of doughs of different flours. *Cereal Chem.*, **74**, 49 (1997)
26. Lai, C. S., Hoseney, R. C. and Davis, R. C. : Effects of wheat bran in breadmaking. *Creal Chem.*, **66**, 217 (1989)
27. Frazier, P. J., Leigh-Dugmore, F. A., Daniels, N. W. R., Russel Eggitt, P W. and Cappock, J. B. M. : The effect of lipoxygenase action on the mechanical development of wheat flour doughs. *J. Sci. Food Agric.*, **24**, 421 (1973)
28. Frazier, P. J., Brimblecombe, F. A., Daniels, N. W. R. and Russel Eggitt, P. W. : The effect of lipoxygenase action on the mechanical development of dough from fat-extracted and reconstituted wheat flours. *J. Sci. Food Agric.*, **28**, 247 (1977)
29. Graveland, A. : Analysis of lipoxygenase non-volatile reaction products or linoleic acid in aqueous cereal suspensions by urea extraction and gas chromatography. *Lipids*, **8**, 599 (1973)
30. Pyler, E. J. : *Baking Science and Technology*. 3rd ed., Sosland Pub. Co., Merriam, KS, p. 262 (1988)
31. Lillard, D. W., Seib, P. A. and Hoseney, R. C. : Isomeric ascorbic acids and derivatives of L-ascorbic acid: their effect on the flow of dough. *Cereal Chem.*, **59**, 291 (1982)
32. Kauffman, S. P. : Dough rheology-a review of structural models and the role of disulfide interchange reactions. *Cereal Foods World*, **31**, 820 (1986)
33. Sullivan, B. : Wheat protein research fifty years of progress. *Cereal Sci. Today*, **10**, 338 (1965)
34. Krog, N. : Theoretical aspects of surfactants in relation to their use in breadmaking. *Cereal Chem.*, **58**, 158 (1981)
35. Hoseney, R. C. : Gas retention in bread dough. *Cereal Foods World*, **29**, 305 (1984)
36. Elton, G. A. H. and Fisher, N. : A technique for the study of the baking process, and its application to the effect of fat on baking dough. *J. Sci. Food Agric.*, **17**, 250 (1966)
37. Junge, R. C. and Hoseney, R. C. : A mechanism by which shortening and certain surfactants improving loaf volume in bread. *Cereal Chem.*, **58**, 408 (1981)

(Received January 18, 1999)