新奇分級粉、ワキシー・ハイアミロース小麦粉の機能性ならびに加工特性に関する研究

誌名	Journal of applied glycoscience
ISSN	13447882
著者名	前田,智子
発行元	日本応用糖質科学会
巻/号	56巻1号
掲載ページ	p. 35-45
発行年月	2009年1月

J. Appl. Glycosci., **56**, 35–45 (2009)

Award Address: Distinguished Young Scientist Award of the 2008's JSAG

Studies on the Functional and Processing Properties of Novelty Polished, Waxy and High-amylose Wheat Flours

(Received October 3, 2008; Accepted October 31, 2008)

Tomoko Maeda[1,*]

[1]*Department of Science, Technology, and Human Life, Graduate School of Education, Hyogo University of Teacher Education (942–1, Shimokume, Kato, Hyogo 673–1494, Japan)*

Abstract: Functional and processing properties of novel wheat flours, such as polished, waxy and high-amylose wheat flours were determined. Polished flours increased the amounts of minerals and anti-oxidant activity, and the amounts of dietary fibers, phytic acids, ferulic acids and pentosans were 2, 3, 10 and 2 times more, and large amounts of damaged starches and higher maltose values were obtained, as compared with the common flour of CW. The distributions of proteins in polished flours were different depending on the portions (fractions) of wheat grains, and proteins of the innermost fraction showed low-allergic reactions. Baking method including long fermentation significantly improved the baking properties of polished flours, and especially sourdough method increased the free amino acids, reducing sugars and organic acids during fermentation. The CO_2 gas in polished-flour-sourdoughs distinctly increased, and their pH, total titratable acidity levels and buffering capacity were significantly better than the CW-sourdough. As a result, the growth of lactic acid bacteria and yeasts in polished-flour-sourdoughs were accelerated during fermentation, and its substituted breads with middle or innermost fractions improved baking qualities having favorable volatile compounds, such as iso-butanol and β-phenyl ethyl alcohol, more than CW-sourdough bread. In contrast, waxy wheat flours improved the staleness of breadcrumbs during storage and its freshness after reheating, while high-amylose wheat flours increased amounts of resistant starch in breadcrumbs during storage. Moreover, waxy wheat flours increased viscous and sticky textures of boiled-noodles, and high-amylose wheat flours suppressed the damage of noodles during boiling with the similar qualities to the durum pasta. Consequently, these novel wheat flours would be sufficient foodstuffs with excellently nutritious, functional and processing properties to give additional values of new taste or functionality to their final products.

Key words: polished wheat flour, waxy wheat flour, high-amylose wheat flour, bread, noodle

Recently, whole wheat grain flours have been focused as new food materials from the view points of high nutritional and functional values including dietary fibers, minerals and antioxidants. However, the practical utilization of whole wheat flour has not been so common in Japan as compared with USA or Europe for our daily diet, and the whole wheat flour could not be used for daily meals. Wheat flour has been normally thought to be white because of the removal of bran or germ. Therefore, milling companies have made much effort to remove the bran or germ from the wheat grain as an ultimate purpose. In whole grains, pericarp (13%), endosperm (85%) and germ (2%) are good sources for the supplement of vitamins, minerals and other dietary fibers,[1] however the conventional milling method recovers 70% of the flour from whole grains. The bran and germ contain various functional and nutrient good components for our health, and also the removal of these materials is considered to be a serious problem because of the environmental pollution and high cost. To resolve these problems, a new wheat flour was prepared from the outer layer to the inner layer of the whole wheat grain using gradually polishing manner by 10% of total wheat weight as reported previously.[2-11]

* Corresponding author (Tel. & Fax. +81–795–44–2193, E-mail: mtomoko@hyogo-u.ac.jp).

Generally, some of commercial whole wheat grain flours are prepared by the conventional milling method including conditioning, breaking, grading, purification and reduction processes, and all the milled fractions are combined altogether like the composition of the original grain. But, the present polishing method did not include the processes as described above, and it is quite easy without any side-production, and the resultant polished flours obtained from the whole grain were expected to have the similar nutritional value to the commercial whole grain flours.

On the other hand, wheat (*Triticum aestivum* L.) starch normally contains about 20–30% amylose, and the rest is amylopectin. Wheat grains containing various ratios of amylose and amylopectin in wheat starch have been developed by genetic recombination. In wheat, at least four kinds of proteins, i.e., waxy protein and three starch granule proteins (SGP-1, -2, -3), tightly bind to starch granules and are responsible for starch synthesis.[11] The waxy protein is a granule-bound starch synthase (GBSS) and is responsible for amylose production.[12] The waxy (amylose-free, glutinous) wheats have been produced in Japan and elsewhere,[13-15] and their characteristics of waxy type wheat flours have been studied by before papers.[16-20] The starch granule protein SGP-1 is responsible for amylopectin synthesis.[12] Therefore, if the wheat grain genetically lacks SGP-1, the wheat can produce a novel high-amylose starch and be used to expand variation in wheat starch.[12] The quality of domestic wheat flour is much lower than that of imported wheat flours, and consequently it is used only for noodle making in Japan. Domestic wheat flour has been recently used for a limited number of other processed foods. However, to be able to use it for a greater number of processed foods, much research is needed to understand the physico-chemical properties of its starch.

In the present study, the authors focused on these novel wheat flours such as polished, waxy and high-amylose wheat flours, their functional properties and practical applications to bread and noodle makings were studied.

MATERIALS AND METHODS

Flours and Chemicals. Polished flours were prepared from a hard-type wheat grain 1CW (No. 1 Canada Western Spring Red) by the same polishing-grading method using a rice-polisher as reported previously.[2-11),21] The eight fractions of polished flours: C-1 (100–90%), C-2 (90–80%), C-3 (80–70%), C-4 (70–60%), C-5 (60–50%), C-6 (50–40%), C-7 (40–30%) and C-8 (30–0%) were prepared from 1CW, and C-1, C-5 and C-8 were used for breadmaking in the present study. The conventionally milled flour prepared from 1CW was named as CW, and it was used for the control flour.

For the normal amylose content sample, non-waxy wheat flour, Chinese Spring (CS) was test-milled from Okumoto Flour Milling Co., Ltd. (Osaka, Japan) and the wheat flour was named as CSF. High-amylose wheat was bred from (Kanto 79/Turkey 116) F_2 // Chousen 57.[12] The variant high-amylose progeny, such as F_5 and F_6 having no SGP-1 were selected, and F_5 and F_6 seeds were harvested at Tsukuba in 1999 and at Morioka in 2000, respectively. In contrast, waxy wheat was selected from the F_2 progeny from CS (Kanto 107 7A)/CS (Kanto 107 4A) //CS (Bai Huo 7 D) and backcrossed twice to the normal CS.[22] This line was confirmed to be nearly isogenic to CS with respect to agronomic performance and chain-length distribution in amylopectin structure.[23] These high-amylose and waxy wheats were also test-milled by Okumoto Flour Milling Co., Ltd. (Osaka, Japan) and named as HAWF and WWF, respectively. As to the control, a commercial hard-type wheat flour, Hermes (Okumoto Flour Milling Co., Ltd., Osaka, Japan) was also used.

Except for these wheat flours, flours of buckwheat, durum and Norin 61 donated from some flour companies in Japan, and Glenlea and Hokushin cultivated in Hokkaido were also used for the following experiments. Dry baker's yeast was donated from J.T. Foods Co., Ltd. (Shizuoka, Japan), other additives were commercial products in Osaka, and other all chemicals were of reagent graded without further purification for the present analyses.

General analyses. Characteristics of flours, such as moisture, ash, protein, dietary fiber and water-soluble pentosan were determined as reported previously.[5] Mineral contents of flours were measured using a fluorescent X-ray elemental analyzer MESA-500 (Horiba Instrument Co., Ltd., Osaka, Japan), as studied previously.[5] Damaged starch, maltose value, activities of some enzymes of flours were determined by AACC procedures used in previous reports.[5]

Functional properties. Amounts of polyhenol by Folin-Denis method, ferulic acids,[24] phytic acids[25] and anti-oxidant activity[26] of flours were determined. In addition, to determine the properties of proteins, the immunoreactivity of wheat-allergy-specific human IgE to the fractionated wheat proteins was measured as reported previously.[27] Resistant starch was determined by using Megazyme Assay Kit (K-RSTA 08/05) according the AACC method (**32-40**).[28]

Flour qualities. Mixing, maturation and gelatinization properties of flours were determined by Brabender apparatuses according to the AACC methods of **54-21**, **54-10** and **22-12**, respectively.[28]

Preparation of dough and bread. In the present study, four kinds of baking methods were used for finding the optimum baking methods for polished flours.[7] Namely, optimized straight method (**OSM, AACC 10-10B**),[28] long fermentation method (**LFM, AACC 10-09**),[28] sponge dough method (**SDM, AACC 10-11**)[28] and

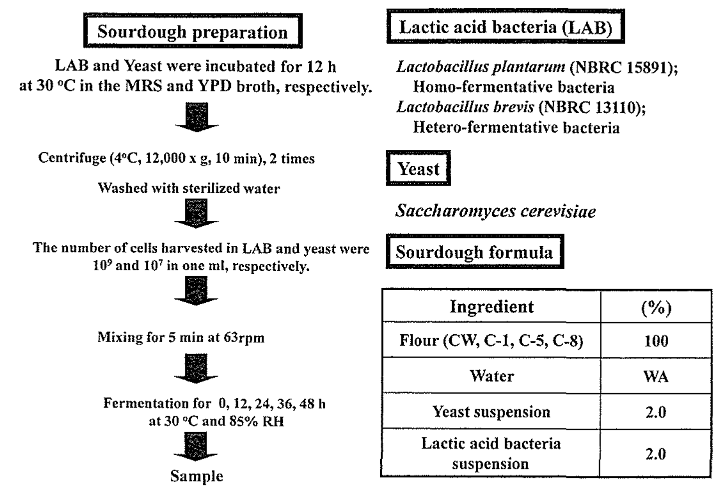

Fig. 1. Flowchart of preparation of sourdough samples.

CW, common hard-type wheat flour; polished flours C-1 (100–90%), C-5 (60–50%), C-8 (30–0%) of the whole grain. WA, water absorption value from fariongraph mixing.

no-time method (**NTM**)[29] were used. In addition, sourdough was prepared by using two kinds of lactic acid bacteria as shown in Fig. 1. The 10–30% of CW was substituted with thus prepared sourdoughs, and sourdough breads were made by OSM as described above.[10] Properties of thus prepared sourdoughs and breads were measured as reported previously.[10]

Baking properties. After baking, the bread was taken out from the oven and the loaf was weighed immediately, and the specific loaf volume was measured by the rapeseed displacement method after standing for 40 min at room temperature.[7,30] The bread qualities were measured using a Fudoh Rheometer (Rheotec Co., Ltd., Tokyo, Japan) with the same method as reported previously.[7,10,31,32] Thus obtained all data were processed using the Rheosoft TR-06 computer program (Rheotech Co., Ltd., Tokyo, Japan).

Isolation of the volatile compounds by headspace sorptive extraction. Volatile compounds in flour and bread samples were determined by headspace sorptive extraction method using a GC-MS as reported previously.[8,9] Identifications of volatile compounds were based on GC retention time, and mass spectra of unknowns were compared with those of authentic standard compounds in a Private Library System developed by using authentic standard samples. For the bread samples, two kinds of breads made by sourdough- and straight-common-methods, as reported previously.[9]

Scanning Electron Microscopy (SEM). For SEM observation of various dough samples, a small portion was obtained from mixed or fermented doughs as reported previously.[5] The small portion was frozen and lyophilized by the same methods used in the previous reports.[33] Thus prepared samples were coated with Pt-Pd for 4 min before observation, and SEM apparatus (Hitachi Model S-800, Tokyo, Japan) was operated at 10 kV according to the same procedure as reported previously.[5]

Differential Scanning Calorimetry (DSC) of breadcrumbs. The DSC (Model DSC-50, Tokyo, Japan) data were obtained by using the freeze-dried breadcrumbs, according to the method of Biliaderis *et al*.[34] 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. The analyses were carried out in triplicate using 3 to 5 mg of sample and its 2.5 fold of water. The samples were programmed at a rate of 10°C/min from approximately 25 to 120°C.

Method of refreshing of bread. To determine the effect of reheating of breadcrumbs after storage, the firmness, adhesiveness and chewing property of reheated bread were measured by the modified refreshing method of Ghiasi *et al*.[35] A slice of bread after storage for various days was wrapped with an 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 same apparatus and method as reported previouly.[32]

Noodle preparation. The noodle was prepared by mixing flours using a Haussler noodle apparatus (Model PN100) and slowly adding (20 s) distilled water and additives as shown in Table 1. After mixing (120 rpm) for 10 min, direction of the mixing screw is reversed, and the resulting dough was extruded at 40°C for obtaining noodle strands with a diameter of 1.75 mm. To avoid attachment for each strand, dry air was sent by an electric fan. Thus prepared noodle samples (100 g) with 20 cm length were boiled by AACC method (**66-50**)[28] as reported previously.[21] The 20 g strands with length of 8 cm were boiled with 300 mL of distilled water in 500 mL of beaker. After washing the boiled-noodles with distilled water of 50 mL three times, removing the water completely by using the Buchner filter, placed to dry in alminium foil at room temperature for 10 min, followed by experimental determinations of noodles and boiling waters as described below.

Characteristics of noodles and boiling water. The fracture and tensile stresses of boiled-noodles were evaluated by using a rheometer RT-2002D (Rheotech Co., Ltd., Tokyo, Japan) as reported previously.[21] The lengths of noodles for fracture and tensile tests were 2 and 6 cm, respectively. The strands were cut by an edge-type plunger at compression depth of 99%, and stretched by specific tools at 6 cm/min of speed, as reported previously.[21] In addition, to the stability of the noodles during boiling, the qualities of boiling water, such as turbidity and cooking loss were also measured by reported previously.[21] The turbidity of boiling water after sufficient homogenate was

Table 1. Summary of ingredients for making noodles.

Sample	Flour			Water	Salt	Egg	Oil
	Norin 61	1CW	Other flours				
Norin 61	500	0	0	170	10	0	0
1CW	0	500	0	170	10	0	0
Durum	0	0	250	75	5	0	0
Glenlea	0	0	500	170	10	0	0
High-amylose	0	0	250	85	5	0	0
Norin 61 (Egg & Oil)	500	0	0	50	10	117	50
Norin 61+1CW55	250	250	0	170	10	0	0
Hokushin+1CW55	0	250	250	170	10	0	0
High-amylose+1CW55	0	125	125	85	5	0	0
Waxy wheat+1CW55	0	150	150	102	6	0	0
Durum+1CW55	0	250	250	155	10	0	0
Norin 61+1CW64	300	200	0	170	10	0	0
Buckwheat+1CW64	0	200	300	200	10	0	0

Table 2. Summary of characteristics of various wheat flours.

Wheat flour	General analysis				Amount of mineral					
	Moisture (%)	Ash (%)	Protein (%)	Dietary fiber (%)	S (%)	Cl (%)	K (%)	Ca (ppm)	Fe (ppm)	Ni (ppm)
CW	12.3	0.2	12.3	2.1	0.17	0.05	0.10	250	19.3	1.3
C-1	11.1	4.3 (21.5)	16.1	32.8 (15.6)	0.27	0.10	1.04	1030 (4.1)	270.2 (14.0)	2.1
C-5	9.1	1.0 (5.0)	13.9	5.7 (2.7)	0.20	0.08	0.30	410 (1.6)	48.3 (2.5)	1.7
C-8	6.9	0.5 (2.5)	8.1	3.8 (1.8)	0.14	0.07	0.15	270 (1.1)	31.8 (1.6)	1.6

Wheat flour	Water-soluble pentosan (%)	Damaged starch (%)	Diastatic activity (mg/10 g flour)	Proteolytic activity (HUT/10 g flour)	α-Amylase activity (U/g flour)	β-Amylase activity (U/g flour)
CW	0.74	15.47	267	167.8	11.6	2.09
C-1	0.59	16.54	486	12.3	11.0	3.19
C-5	1.09 (1.5)	39.06 (2.5)	618 (2.3)	5.6	11.1	2.88
C-8	0.80 (1.1)	27.95 (1.8)	618 (2.3)	168.1	11.2	1.67

Abbreviations are the same as in Fig. 1. Diastatic activity: mg of maltose formed, HUT, hemoglobin units on tyrosine basis. Values in the parentheses are ratios to those of the control flour, CW.

determined at 660 nm by photometer (UV-160A Shimazu Co., Ltd., Kyoto, Japan) and thus boiling water of 10 g was freeze-dried and the changing ratio of the weight of noodles between before and after boiling was measured as cooking loss.

Statistical analysis. The results were statistically analyzed by variance (ANOVA), and significant differences among samples were evaluated by Duncan's and Tukey's multiple-range tests (p<0.05) using SPSS (Version 11.0; SPSS Inc., Chicago, IL).

RESULTS AND DISCUSSION

Characteristics of polished flours.

General analyses, functional properties and flour qualities.

Polished flours contained more amounts of ash, dietary fibers and minerals including Ca and Fe as shown in Table 2,[5,10] as compared with CW of common flour. In addition, the water-soluble pentosans and damaged starches with higher maltose values were shown in polished flours more than CW.[5,10] Functional compounds of polyphenol, phytic acids, ferulic acids and anti-oxidant activity were also increased, as compared with the CW (data not shown).

Properties of protein.

The proteins of polished flours were fractionated and different distributions were shown depending on the each fraction (Table 3).[27] In addition, the albumin/globulin, glutenin and gliadin proteins obtained from the polished flours were tested for the allergen assay with immunodetection using the sera of wheat allergenic patients. Especially, albumin/globulin groups in all fractions showed different IgE-reactivity patterns, and the 60–75 kDa proteins appeared in all of fractions, and were higher in the C-3-C-5 fractions (Fig. 2). Fractions C-3 and C-4 contained larger amounts of specific wheat allergenic proteins including 60–75, 35, 22 and <20 kDa. Immunoblotting results confirmed that C-8 of the innermost fraction contained a smaller amount of allergenic proteins, as compared with other fractions (Fig. 2). Therefore, the polishing method was considered to be appropriate to obtain hypoallergenic wheat flours, and the fraction C-8 may be possible to be consumed by people suffering from wheat allergy.[27]

Table 3. Compositions of proteins in polished flours.

(g/100 g flour)

Fraction	Albumin/Globulin	Gliadin	Glutenin
C-1	4.50[ab]	0.43[a]	1.28[a]
C-2	5.43[a]	1.09[b]	1.48[a]
C-3	3.93[abc]	1.53[b]	1.77[a]
C-4	3.84[abc]	1.44[b]	1.55[a]
C-5	2.87[bcd]	1.21[b]	1.42[a]
C-6	2.34[cd]	1.34[b]	1.79[a]
C-7	2.16[d]	1.22[b]	1.66[a]
C-8	1.99[d]	1.34[b]	1.68[a]

CW, common hard-type wheat flour; polished flours C-1 (100–90%), C-2 (90–80%), C-3 (80–70%), C-4 (70–60%), C-5 (60–50%), C-6 (50–40%), C-7 (40–30%), C-8 (30–0%) of the whole grain. Values followed by the same letter in the same column are not significantly different at p<0.05 (by Tukey test). n=3.

Effects of various baking methods on dough qualities.

Since the dough and baking properties of polished flours alone were quite poor and could not make sufficient qualities of breads for consumer's requests,[2] and its suitable baking method was evaluated.[7] The SEM images of doughs made by OSM, LFM and SDM were shown after mixing and fermentation (Fig. 3).[7] Although polished flours contained large amounts of dietary fiber to suppress the satisfactory gluten structure for breadmaking, the C-5 dough mixed by these methods appeared to be more viscous than CW dough. Especially, the sticky substance was still observed in C-5 dough mixed by SDM as indicated by arrows. The SEM images of fermented C-5 dough samples were similar to those from CW dough, and polished flours could make a better gluten structure in the dough after mixing and fermentation using LFM and SDM, as compared with other baking methods. These unique appearances of polished flour doughs in SEM images coincided with the results of viscoelasticity of polished flours as reported previously.[7]

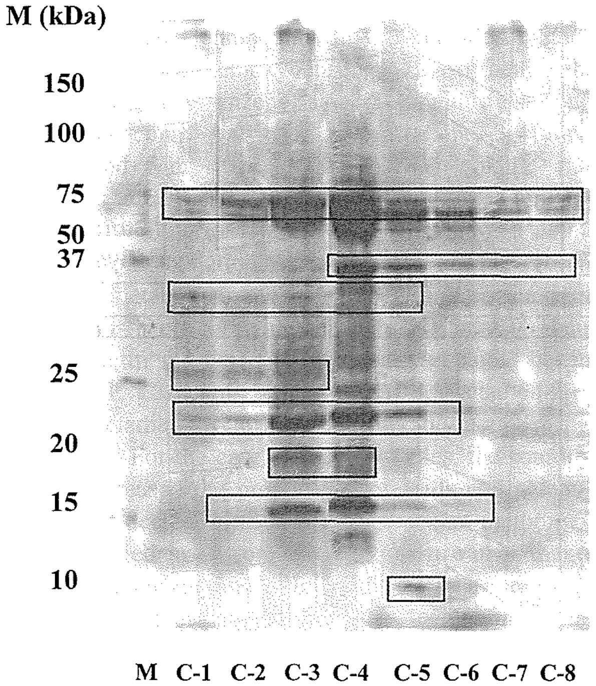

Fig. 2. Reaction of allergy-specific human IgE to albumin/globulin proteins obtained from polished flours.

Abbreviations are the same as in Table 3, except that M is marker.

Effects of various baking methods on bread qualities. Specific loaf volume.

SDM increased the loaf volume of bread baked with all samples as shown in Table 4.[7] The specific volume of bread made from polished flours was lower than that of CW, and the values decreased in the order of C-8, C-5 and C-1. Although there were no significant differences in the results of CW-bread among OSM, LFM and SDM, the specific volume of polished-flour-breads was improved by using SDM, as compared with other baking methods. And especially C-5 bread more significantly increased the loaf volume rather than other methods. In addition, the notable property of C-8 showed that the use of NTM for C-8 significantly increased the specific volume of bread with around 40% more than OSM, while CW bread was distinctly decreased by NTM. The SH residue derived from bran or germ in the innermost fraction of C-8 might be oxidized by L-ascorbic acid and L-cysteine for using of NTM, resulting in the formation of larger loaf volume, as compared with OSM or LFM.

Rheological properties of breadcrumbs during storage.

The firmness of CW breadcrumbs after storage for 2 or 5 days was not significantly different among various baking methods (Fig. 4).[7] Therefore, storage property of CW bread was not affected by the kinds of baking methods. In contrast, the bread made from all polished flours by SDM suppressed the staling of breadcrumbs, as compared with other baking methods. Especially, the softness of breadcrumbs made from C-5 showed quite similar to that from CW, and there were no significant differences in the results after storage for 5 days between the CW and C-5 breads.[7] As to the textural properties of breadcrumbs after baking, C-5 bread made by SDM showed the significantly higher elasticity than other samples after storage for 0 and 5 days, and also cohesiveness of the breadcrumbs after storage for 2 or 5 days were significantly larger than CW breads (data not shown). Furthermore, the ratio of decrease in the cohesiveness for polished flour breads during storage was quite lower than that of CW bread, and this result might be correlated to suppress the staleness of

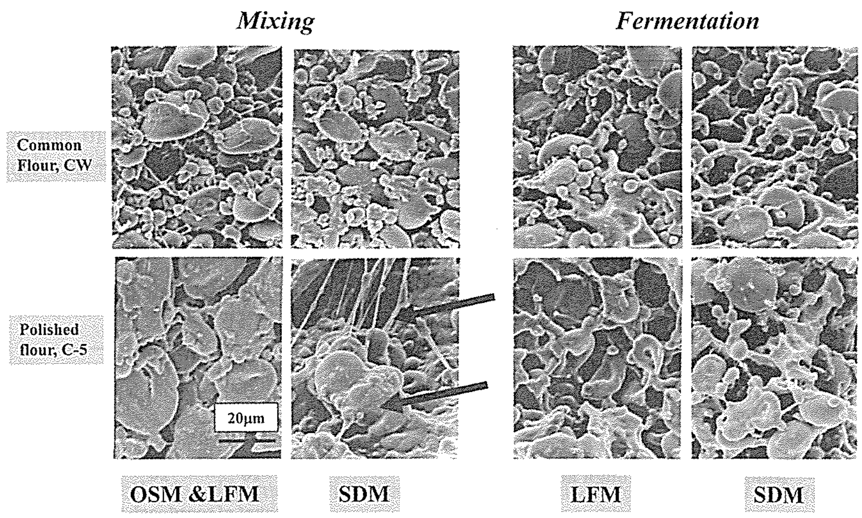

Fig. 3. SEM images of mixed or fermented doughs by various baking methods.

Abbreviations are the same as in Fig. 1. OSM, LFM and SDM are optimized-straight, long-fermentation and sponge-dough methods, respectively.

Table 4. Effects of various baking methods on specific volume of breads.

Samples	Specific volume (cm³/g)			
	OSM	LFM	SDM	NTM
CW	4.72[ab]	5.27[b]	5.49[b]	4.23[a]
C-1	1.12[a]	1.35[a]	1.30[a]	1.27[a]
C-5	1.76[a]	1.88[a]	2.25[b]	1.83[a]
C-8	1.91[a]	2.03[a]	2.35[b]	2.35[b]

Abbreviations are the same as in Fig. 4. Values followed by the same letter in the same row are not significantly different at $p<0.05$ (Duncan test). $n=5$.

breadcrumbs.

Qualities of sourdough breads.

Since the LFM and SDM including long fermentation improved the dough and bread qualities of polished flours, the sourdough was prepared with polished flours.[10] The sourdough-method increased the free amino acids, reducing sugars, organic acids in polished-flour-doughs during fermentation. The pH, total titratable acidity levels and buffering capacity of sourdoughs made from polished flours were significantly different from those of the con-

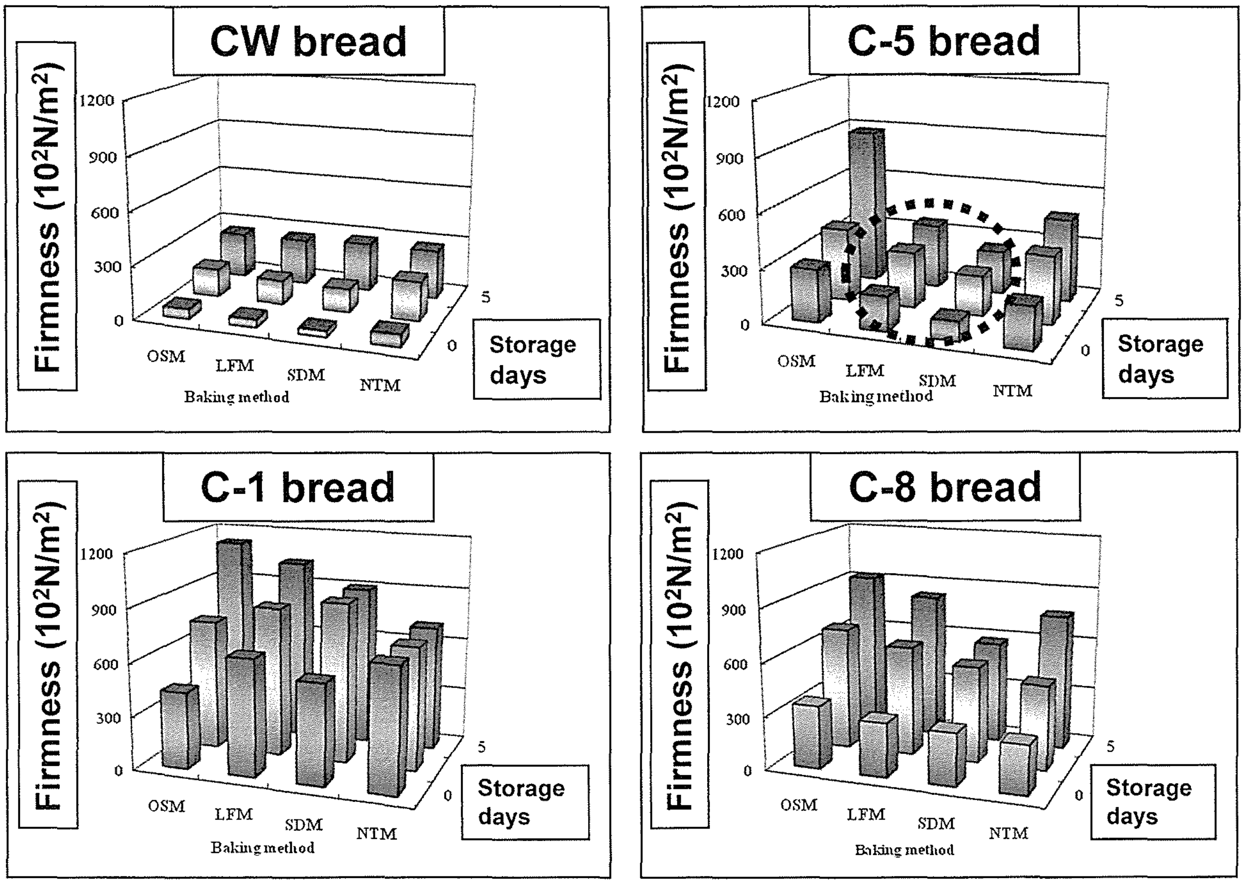

Fig. 4. Effects of various baking methods on hardening of breadcrumbs during storage.

Abbreviations and experimental conditions are the same as in Fig. 3, except that NTM is no-time method.

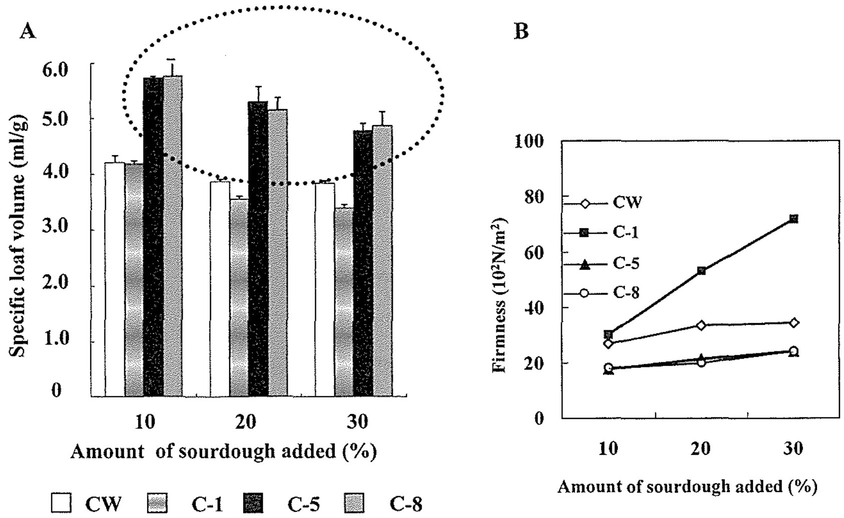

Fig. 5. Baking properties of CW including various sourdough samples at 10–30% levels (*L. brevis*+*S. cerevisiae*).

Abbreviations are the same as in Fig. 1.

trol sourdough with CW, and they were sufficient for providing better qualities of sourdough breads rather than CW.[10] The growth of lactic acid bacteria and yeasts in polished-flour-sourdoughs were significantly accelerated during fermentation than in CW-sourdough. Higher maturation of polished flour sourdoughs softened the hardness of mixed dough, and then the substitutions of C-5 or C-8 sourdoughs for CW significantly increased the loaf volume (Fig. 5A) and softened breadcrumbs more than CW sourdough (Fig. 5B).[10] Therefore, the application of polished flours to sourdough bread would improve rheological properties of dough and breads, as compared with CW sourdough.

Volatile flavors of flour and bread.

A total of 48 volatile flavor compounds determined in all samples were common as in the wheat grain or flour.[8] The major volatile compounds in C-1 included methoxybenzene (i.e. 1,4-dimethoxybenzene, 1,2,4-trimethoxybenzene, 1,2-dimethoxybenzene) associated with musty odors, and nitrogen compounds (i.e. trimethylamine, 3(4)-methyl pyridine and 3-methoxy pyridine). The volatile flavor compounds identified in C-5 and C-8 were similar to those in CW. But, some compounds that have a connection with both oxidation products from unsaturated fatty acids and metabolites of many species associated with moldy grains, were more abundant in C-5 and C-8 than in CW. Furthermore, hexanal, methanol, ethanol, hexanol, 1-octen-3-ol, 3-octen-2-one, (E,Z)-3,5-octadien-2-one, (E,E)-3,5-octadien-2-one were considerably abundant in C-5 and C-8.[8] For the case of bread samples, the sourdough-method increased the proportions of acids and aldehydes in crust, but decreased those of alcohols and methoxybenzenes identified in the outermost fraction, rather than the straight-common-method.[9] In addition, the sourdough-method lowered the amounts of some compounds related to oxidation products from unsaturated fatty acids and metabolites of species with moldy grains, as compared with the straight-common-method. Furthermore, the amounts of 2-methyl-propeanol (iso-butanol) and 2-phenylethanol (β-phenyl-ethyl-alcohol) that have been known as favorable flavor compounds on breadmaking distinctly increased in polished-flour-breads than CW-bread, regardless of baking methods. Therefore, the sourdough-method with lactic acid fermentation would be suitable baking procedure for polished flours from the viewpoints of flavor properties. Furthermore, the utilization of sourdough-method for polished flours from middle and innermost fractions might be appropriate to taste and texture of consumers' request for bread qualities.[9]

Characteristics of waxy and high-amylose wheat flours.

Baking results.

The twenty (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.[32] 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 20 WWF and 40 WWF. Furthermore, the 20 and 40 WWF softened breadcrumbs, as compared with Hermes, and retarded the staleness of breadcrumbs during storage.[32] The WWF softened the breadcrumbs with the increasing ratio of substitution, whereas CSF could harden it with the increase. On the other hands, the specific volume and storage properties of breads with HAWF could not be improved distinctly, but the amounts of resistant starch in the breads were increased during storage, and especially the amounts were larger in order of the added amounts of HAWF.[36]

Table 5. Effects of waxy and high-amylose wheat flours on refreshing of breadcrumbs by reheating.

Sample	Before heating			After heating		
	Firmness (10^2 N/m^2)					
	Storage day			Storage day		
	3	5	7	3	5	7
CSF	789.1^a	925.1^a	1029.5^a	1045.1^b	1707.4^b	1063.6^a
HAWF	524.2^a	662.0^a	773.2^a	628.9^b	717.0^a	789.8^a
WWF	356.4^b	409.2^b	632.7^b	171.0^a	262.2^a	181.5^a

Values followed by the same letter of the same day before and after heating are not significantly different at $p<0.05$ (Duncan test). $n=10$. CSF, test milled soft-type wheat from Chinese Spring; HAWF, high-amylose wheat flour; WWF, waxy wheat flour.

Softness of refreshed bread after reheating.

To determine the effects of CSF, HAWF or WWF on refreshing of bread, the firmness of reheated breadcrumbs after storage was measured (Table 5).[32] Regardless of amylopectin contents, amounts of substitution or storage days, all kinds of breadcrumbs were softened by reheating. The breadcrumbs containing WWF could be softened and refreshed more distinctly by reheating, as compared with CSF. Therefore, the substitution of WWF for Hermes was considered to improve not only the softness, but also the refreshing of staled hard breadcrumbs by heating, caused by the high amylopectin content. Consequently, the bread with WWF was expected to be applied for daily diet, and the bread quality was considered to satisfy our diet.

DSC results of breadcrumbs.

DSC data of breadcrumbs stored for 5 days are shown in Table 6. The first endothermic peak was observed between 40–60°C, which is considered to be formed from aged amylopectin gel.[34] The 40 WWF showed the smaller enthalpy than Hermes alone. Therefore, the partial substitution of WWF was suggested to suppress the crystallization of amylopectin, retarding the staleness of breadcrumbs during storage. After the 5-days stored sample is reheated at 110°C, it was freeze-dried and analyzed in DSC. The endothermic peak of reheated and freeze-dried bread sample has been reported to become much smaller than that of non-reheated sample.[35] In the present study, the enthalpy of aged amylopectin for all tested samples after reheating at 110°C, was decreased, as 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 the high tempera-

Table 6. Effect of substitution with waxy wheat flour for common wheat flour on retrogradation of starch.

Sample	Storage day	T_{i1} (°C)	T_{p1} (°C)	T_{r1} (°C)	Δh_1 (J/g)	T_{i2} (°C)	T_{p2} (°C)	T_{r2} (°C)	Δh_2 (J/g)
Hermes-A	5	46.67	52.32	55.64	1.45	94.75	98.94	107.55	0.75
Hermes-B	5	46.78	51.34	56.06	0.13	93.49	98.46	107.39	1.30
40 CSF-A	5	39.91	49.89	56.54	1.51	89.89	99.82	108.51	0.59
40 CSF-B	5	45.77	53.61	58.77	0.16	89.64	97.16	108.59	1.13
40 WWF-A	5	43.46	52.29	60.75	1.29	97.02	103.55	110.32	0.28
40 WWF-B	5	46.95	52.67	61.31	0.40	90.17	102.07	107.22	0.47

T_i, initial temp.; T_p, peak temp.; T_r, recovery temp.; Δh, enthalpy. 1 and 2 mean the first and second peaks, respectively. n=3. A and B are without and with reheating, respectively. Abbreviations are the same as in Table 5.

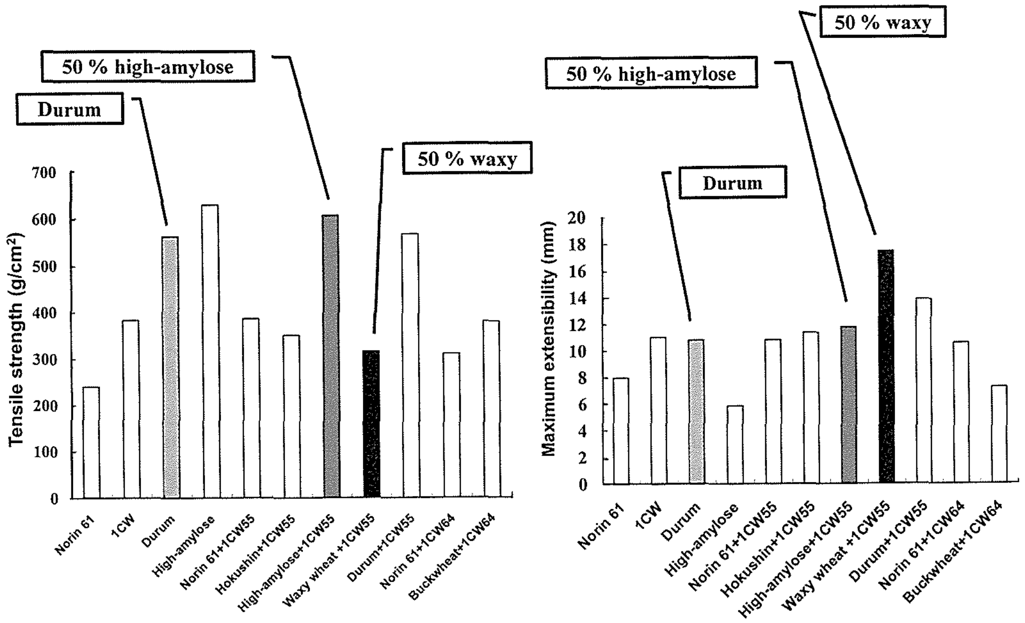

Fig. 6. Effects of various wheat flours on textural properties of boiled-noodles.

ture. Hermes decreased the enthalpy more obviously than the other samples tested. Therefore, Hermes was considered to contain more amount of recrystallized amylopectin in the starch than that of other samples. In contrast, the second melting enthalpy which corresponds to the degradation of amylose-lipid complexes was increased by reheating more than before reheating. For the case of bread, during baking, only the approximately 1% of soluble amylose is leached from starch granule as a soluble amylose by the swelling of starch.[37] When the staled bread was reheated, a portion of the remaining insoluble amylose in the starch granule might be leached out from the starch, strengthen 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 could be accelerated the formation of amylose-lipid complexes by reheating, as compared with 40 WWF.

Noodle qualities.

Additions of WWF and HAWF to the CW of common flour showed the similar fracture stress to that of durum pasta. As to the tensile test, WWF decreased the strength with longer tensile length, while the HAWF somewhat increased the strength, as compared with durum pasta (Fig. 6). In addition, turbidity of boiling water of noodle samples with WWF and HAWF was very clearer, and the cooking loss was depressed by additions of WWF or HAWF, as compared with the durum pasta (Fig. 7). Therefore, WWF and HAWF could suppress the damage of surface of noodles during boiling, followed by the improving textures of boiled-noodles. Especially, WWF increased the viscous and sticky textures of noodles, and HAWF produced the smooth surface of noodles with keeping the similar qualities to the durum pasta.

Functional and processing properties of novel wheat flours, such as polished, waxy, and high-amylose wheat flours were studied. As the polishing-grading method was quite easy and simple milling method without removing bran and germ of wheat, and polished flours included more amounts of ash, dietary fibers and minerals than the CW of common flour. In addition, its flour qualities were quite excellent with much more functional components, and the proteins in the innermost fraction showed low-allergic reactions. Therefore, the polishing process would be also appropriate method to obtain hypoallergenic wheat flours. As to the processing properties, polished flours alone could not make good dough and bread qualities due to the broken gluten structure by much distribution of bran. But the SDM with long fermentation was suitable to improve the poor baking properties of polished flours, and could produce better bread qualities caused by the high

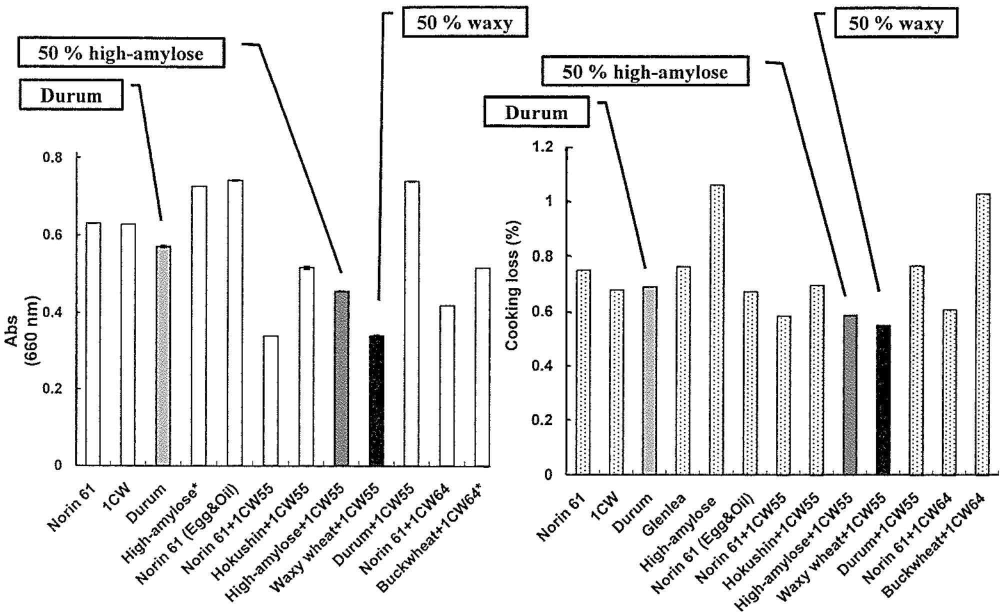

Fig. 7. Effects of various wheat flours on characteristics of boiling water after boiling noodles.

The boiling water samples followed by symbol of asterisk (*) were diluted twice before the turbidity measurement.

maturation and fermentation properties of the dough, as compared with other baking methods. Because the qualities of polished flours, such as suitable acidity and sufficient buffering capacity, attributed to the bran fraction were favorable for better growth and longer life of yeast in the dough during fermentation, their application to sourdough bread would be more appropriate and improve the dough and bread qualities, as compared with CW.

On the other hand, for the case of waxy and high-amylose wheat flours, the waxy wheat flours appeared to suppress the formation of an insoluble network structure of starch during cooling, which improved a tolerance of gelatinized starch to the retrogradation, whereas the high-amylose wheat flours increased the amounts of resistant starches in breadcrumbs during storage. As to the noodle making, both wheat flours improved the texture and stability of the noodles after boiling. From these results, these novel wheat flours improved the bread and noodle qualities, and were expected to be sufficient foodstuffs to have additional values such as functional, nutritional and processing properties to various final products.

I wish to express my sincere thanks and deep gratitude to my advisor and supervisor of former Prof. Dr. Naofumi Morita in Lab. Food Chemistry of Graduate School of Life and Environmental Sciences, Osaka Prefecture University for his kind guidance, technical assistance, advice and support throughout the course of my study. I also wish to my sincere thanks to Dr. Pham Van Hung, Dr. Megumi Miyazaki and Dr. Tri Handoyo and all students in the laboratory. In addition, I express my gratefulness to the Iijima Memorial Foundation for the Promotion of Food Science and Technology for the Grant; the Itomen Co., Ltd. (Hyogo, Japan) for the preparation of polished flours; and Nisshin Flour Milling Co., Ltd. (Tokyo, Japan), Okumoto Flour Milling Co., Ltd. (Osaka, Japan), Miyake Seifun Co., Ltd. (Osaka, Japan), Mitsubishi-Kagaku Foods Co., Ltd. (Tokyo, Japan), Amano Enzyme Inc. (Aichi, Japan) and J.T. Foods Co., Ltd. (Shizuoka, Japan) for donating of flours, yeasts and additives.

REFERENCES

1) Y. Pomeranz: Chemical composition of kernel structures. in *Wheat: Chemistry and Technology*, Vol. 1, Y. Pomeranz, ed., 3rd Ed., AACC, St. Paul, p. 99 (1988).
2) T. Maeda, M. Ohkura and N. Morita: Characterization of wheat flour graded by polishing and its application to breadmaking. *J. Appl. Glycosci.*, **46**, 413–422 (1999).
3) T. Maeda and N. Morita: Effect of polished-graded flour substitution to commonly milled wheat flour on the properties of dough and bread. *J. Appl. Glycosci.*, **47**, 1–12 (2000).
4) T. Maeda, N. Maeda and N. Morita: Effect of polished-graded hard-type wheat flour substitution for commonly milled hard-type wheat flour on the properties of dough and bread. *J. Appl. Glycosci.*, **48**, 27–36 (2001).
5) T. Maeda and N. Morita: Effect of quality of hard-type polished-graded flour on breadmaking. *J. Appl. Glycosci.*, **48**, 63–70 (2001).
6) T. Maeda and N. Morita: Flour quality and pentosan prepared by polishing wheat grain on breadmaking. *Food Res. Inter.*, **36**, 603–610 (2003).
7) T. Maeda, J.H. Kim and N. Morita: Evaluation of various baking methods for polished wheat flours. *Cereal Chem.*, **81**, 660–665 (2004).
8) T. Maeda, J.H. Kim, Y. Ubukta and N. Morita: Analysis of volatile compounds in polished-graded wheat flours using headspace sorptive extraction. *Eur. Food Res. Technol.*, **227**, 1233–1241 (2008).
9) T. Maeda, J.H. Kim, Y. Ubukta and N. Morita: Analysis of volatile compounds in polished-graded wheat flour bread using headspace sorptive extraction. *Eur. Food Res. Technol.*, **228**, 457–465 (2009).
10) J.H. Kim, T. Maeda and N. Morita: Application of polished-graded wheat grains for sourdough bread. *Cereal Chem.*, **82**, 144–151 (2005).
11) J.H. Kim, T. Maeda and N. Morita: Effect of fungal α-amylase on the dough properties and bread quality of wheat flour substituted with polished flours. *Food Res. lntern.*, **39**, 117–126 (2006).
12) M. Yamamori, S. Fujita, K. Hayakawa, J. Matsuki and T. Yasui: Genetic elimination of starch granule protein, SGP-1, of wheat generates an altered starch with apparent high amylase. *Theor. Appl. Genet.*, **101**, 21–29 (2000).
13) T. Nakamura, M. Yamamori, H. Hirano, S. Hidaka and T.

Nagamine: Production of waxy (amylose free) wheats. *Mol. Gen.Genet.*, **248**, 253–259 (1995).
14) C. Kiribuchi-Otobe, T. Nagamine, T. Yanagisawa, M. Ohnishi and I. Yamaguchi: Production of hexaploid wheats with waxy endosperm character. *Cereal Chem*, **74**, 72–74 (1997).
15) T. Yasui, J. Matsuki, T. Sasaki and M. Yamamori: Waxy endosperm mutants of bread wheat (*Triticum aestivum* L.) and their starch properties. *Breed. Sci.*, **47**, 161–163 (1997).
16) M. Yamamori and N.T. Quynh: Differential effects of Wx-A1, -B1 and -D1 protein deficiencies on apparent amylose content and starch pasting properties in common wheat. *Theor. Appl. Genet.*, **100**, 32–38 (2000).
17) E. Araki, H. Miura and S. Sawada: Identification of genetic loci affecting amylase content and agronomic traits on chromosome 4A of wheat. *Theor. Appl. Genet.*, **98**, 977–984 (1999).
18) E. Araki, H. Miura and S. Sawada: Differential effects of the null alleles at the three Wx loci on the starch-pasting properties of wheat. *Theor. Appl. Genet.*, **100**, 113–120 (2000).
19) S. Fujita, H. Yamamoto, Y. Sugimoto, N. Morita and M. Yamamori: Thermal and crystalline properties of waxy wheat (*Triticum aestivum* L.) starch. *J. Cereal Sci.*, **27**, 1–5 (1998).
20) H. Miura and A. Sugawara: Dosage effects of the three Wx genes on amyloase synthesis in wheat endosperm. *Theor. Appl. Genet.*, **93**, 1066–1070 (1996).
21) T. Maeda, Y. Kaneshiro and N. Morita: A natural improver for starch retrogradation in noodle during storage. in *Proceedings of the 58th RACI Cereal Chemistry Division Conference*, Gold Coast (2008) (in press).
22) H. Miura, E. Araki and S. Tarui: Amylose synthesis capacity of the three *Wx* genes of wheat cv. Chinese Spring. *Euphytica*, **108**, 91–95 (1999).
23) H. Miura, M.H.A. Wickramasinghe, R.M. Subasinghe, E. Araki and K. Komae: Development of near-isogenetic lines of wheat carrying different null *Wx* alleles and their starch properties. *Euphytica*, **123**, 353–359 (2002).
24) C. Nishizawa, T. Ohta, Y. Egashira and H. Sanada: Ferulic acid contents in typical cereals. *Nippon Shokuhin Kagaku Kaishi*, **45**, 499–503 (1998) (in Japanese).
25) M. Latta and M. Eskin: A simple and rapid colorimetric method for phytate detemination. *J. Agric. Food Chem.*, **28**, 1313–1315 (1980).
26) S. Matsuda and Y. Kudoh: Ferulic acid contents in *Mugi Miso* (Barley-*koji Miso*) and antioxidative activity of *Mugi Koji* (Barley-*koji*). *Nippon Shokuhin Hozou Kagaku Kaishi*, **26**, 199–203 (2000) (in Japanese).
27) T. Handoyo, T. Maeda, M. Akagawa, T. Mitsunaga and N. Morita: Development of hypoallergenic wheat flour by stepwise polishing. *Inter. J. Food Prop.*, **10**, 1–8 (2007).
28) American Association of Cereal Chemists: *Approved Methods of the AACC*, 10th ed., Method 10–09, 10–10B, 10–11, 22–12, 32–40, 54–10, 54–21 and 66–50. The Association, St. Paul (2000).
29) A.E. Baker, W.T. Doerry, K. Kulp and K. Kemp: A response-surface analysis of the oxidative requirements of no-time doughs. *Cereal Chem.*, **65**, 367–372 (1988).
30) T. Maeda, T. Hashimoto, M. Minoda, S. Tamagawa and N. Morita: Effects of mutant thermostable α-mylases on rheological properties of wheat dough and bread. *Cereal Chem.*, **80**, 722–727 (2003).
31) N. Morita, T. Maeda, M. Miyazaki, M. Yamamori, H. Miura and I. Ohtsuka: Dough and baking properties of high amylose and waxy wheat flours. *Cereal Chem.*, **79**, 491–495 (2000).
32) N. Morita, T. Maeda, M. Miyazaki, M. Yamamori, H. Miura and I. Ohtsuka: Effect of substitution of waxy-wheat flour for common flour on dough and baking properties. *Food Sci. Technol. Res.*, **8**, 119–124 (2002).
33) K. Nihei, Y. Torikata and M. Kageyama: Structural changes of flour-water dough during mixing process—scanning electron microscopy of flour-water dough after fixation and enzymatic degradation of starch granules—. *Nippon Shokuhin Kogyo Gakkaishi*, **37**, 266–269 (1990) (in Japanese).
34) C.G. Biliaderis, C.M. Page, L. Slade and R.R. Siret: Thermal behavior of amylose-lipid complexes. *Carbohydr. Polym.*, **5**, 367–371 (1985).
35) K. Ghiasi, R.C. Hoseney, K. Zeleznak and D.E. Rogers: Effect of waxy barley starch and reheating on firmness of bread-crumbs. *Cereal Chem.*, **61**, 281–285 (1984).
36) P.V. Hung, T. Maeda and N. Morita: Characteristics and functionality of waxy and high-amylose wheats in breadmaking. *Res. Adv. Agric. Food Chem.*, **6**, 79–93(2005).
37) H. Matsumoto: Storage of bread. in *Science of Process in Breadmaking*, Korin, Tokyo, pp. 252–253 (1997) (in Japanese).

新奇分級粉，ワキシー・ハイアミロース小麦粉の機能性ならびに加工特性に関する研究

前田智子[1]
[1] 兵庫教育大学大学院学校教育研究科
(673–1494 加東市下久米 942–1)

古くから小麦は米のように「粒食」することはなく，粒を砕いて粉にした上で種々の食品に加工できる「粉食」形式をとってきた．現在の小麦の製粉システムは，小麦の外皮と胚芽の除去により，美味しさと食べやすさを高めることを目的として開発・発展してきたものである．しかしながら，その一方で，これらの画分に存在する豊富な栄養成分の損失をもたらすに至ったともいえる．本研究での改良型酒米用搗精機の使用により調製される「分級小麦粉」は上述の欠点を補うために著者らにより開発されたものである．すなわち，小麦の外皮と胚芽を除去せず，小麦穀粒の外層部から中心部まで段階的に削り取るという従来とは異なる製粉方法で得られたものである．従って， 従来法での製粉歩留まりを改善するのみならず，栄養性と機能性を保持した新奇な小麦粉である．

分級粉は，ビタミン，ミネラル等を多量に含み，いずれの分級層でも優れた抗酸化能を示すのみならず，大腸癌の予防にもつながる食物繊維を通常粉の2倍以上含有していた．また機能性物質であるフィチン酸，フェルラ酸，ペントサン等は各々3，10，2倍以上，さらに製パン性に影響を及ぼす損傷澱粉やマルトース価も通常粉よりも2倍以上の値を示した． 分級粉単独によるドウ中には，多くの外皮成分がグルテンを切断している形態が顕微鏡で観察され，製パンにおける良好なドウの物性や優れた最終品質を示すことは不可能であった．しかし分級粉ドウは独特の熟成・発酵特性を示し，長時間発酵を伴う製パン方法を用いると製パン性の顕著な改善が認められた．また，乳酸菌を使用したサワードウ法では，分級粉ドウは通常粉よりも多量の遊離アミノ酸，還元糖および有機酸を含み，発酵中の酵母の生育状態に最適なpH下で良好な生地形成を可能とした．その結果，発酵中に多量のガス発生を促進し，焼成後のパンの膨らみとやわらかさの増加，香気特性の改善により，サワーブレッドのような特殊な製パンへの利用が最適であることも明らかとなった．更に，分級法では全粒穀粒から部位別に粉の調製が可能であり，各部位 (分級層) で水溶性・不溶性蛋白質の分布に差がみられた．そこで，各分級層由来の蛋白質を用いて小麦アレルギー患者血清中の特異的IgEをイムノブロッティングで検出した．その結果，内層部ではその反応性が低く，分級法によりアレルゲン性の異なる小麦粉の調製が可能となり，特に内層部の分級粉を用いての低アレルゲン性加工食品の開発が期待された．

一方，ワキシー・ハイアミロース小麦粉は，従来の小麦粉のアミロース/アミロペクチンの比率とは異なり近年新たに開発された穀物である．ワキシー小麦粉は製麺性においてやわらかく，かつ切れにくいモチモチ感を，製パン性では保存性の改善をもたらすことが明らかとなった．特に，製パン性では保存中に硬化したパンを再加熱した場合に， クラムのソフト感回復力を強化した． 一方，ハイアミロース小麦粉による茹麺はデュラム様の物性を示し，茹で汁の吸光度による濁度やcooking lossの値は通常粉より約20%低く，麺表面の肌荒れ抑制効果を示した．従って，ハイアミロース小麦粉添加により加熱中の麺の保形性改善効果がみられ，パスタを含む各種麺への利用が期待された．

以上の結果より， これらの新奇小麦粉の優れた栄養性，機能性と加工特性を生かし，最終製品に独特の食感とテクスチャーを付与することで，新たな美味しさと付加価値のある各種加工食品への展開と応用の可能性を明らかとした．