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Determination of the bread-making quality of flours using an automatic bread machine

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Abstract: In this study, the possibility of bread machine utilization as a quality control tool in the baking industry was investigated. Three different flour samples (F_1, F_2, and F_3) having different protein contents were obtained and then 12% wheat starch and 2% vital gluten were added to these flours to adjust protein ratios. The physicochemical and rheological properties of these flour combinations were analyzed. Specific volume, crumb grain attributes, crust and crumb color, and bread firmness in terms of compressibility (g) were measured. Specific volumes changed between 5.22 and 6.69 mL g^{-1} and between 4.87 and 6.29 mL g^{-1} for hearth and machine bread, respectively. Crumb firmness values of hearth bread made from F_1, F_2, and F_3 flours were 174.2, 259.4, and 180.3 g, whereas the mean firmness values of machine breads made from those flours were 91.2, 157.58, and 154.98 g, respectively. The F_2 flour had the poorest performance in both baking methods with regard to the evaluated features. At the same time, the bread machine performances were different, but displayed similar responses with changing flour quality. The effects of protein content were not observed in hearth bread. However, these changes affected specific volume and crumb features in bread machine baking. The study showed that bread machines with an optimized formula could be successfully employed for determining flour quality in bread making.

Key words: Bread machine, bread quality, flour quality, french bread

Introduction

Due to the high consumption of bread, the baking sector constitutes the most important section of the food industry. Frequently changing quality prevents the development of these industries and often leads to consumer dissatisfaction. Consumer demand is one of the most important factors in the production progress and development. Therefore, technological development of the bread industry is done for the purpose of boosting quality. Additionally, the quality of bread and reducing bread waste are extremely important (Göçmen 2001).

Wheat gluten quantity and quality are closely related to bread quality. Addition of high-quality wheat into the blend and the use of permitted baking additives are recommended to obtain a desirable standard of quality. Moreover, a variety of additives are used to increase the nutritional value of the bread and to delay staleness and spoilage. In particular, the additives used in large-scale bread production facilities for the purpose of balancing changes in flour quality significantly affect the dough rheology and bread features. In the baking industry, widely used additives are oxidants, reducing agents,

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emulsifiers, and enzymes (Stauffer 1983). The roles of components and process steps should be well known in order to correct any faults in the bread and identify the source of the lack or surplus that may arise during production. At the same time, it is possible for knowledgeable and experienced bakery craftsmen to produce quality bread (Doğan 1997).

Professional staff, adequate equipment, and a controlled environment are required to investigate the bread-making potential of flour in baking research institutes and facilities around the world. Flour quality should always be verified with a baking test in any instance of quality consideration.

The millers in Turkey often send flour samples to reputable bakeries and proceed according to their feedback. Alternative approaches are needed to determine the effects of flour, additives, and the other components on bread quality. Hansen and Hansen (1992) investigated the possibility and repeatability of using an automatic bread machine to estimate the attainable bread volume. Czuchajowska and Pomeranz (1993) used a system consisting of a bread machine and a rheofermentometer to assess gas formation and retention. Faa et al. (1994) used an automatic bread machine to optimize the bread formula and reported promising results. In determining the quality of flour for bread making, a method that is easy to apply and practical is needed. Because of the changes in wheat quality from year to year, the analysis must be repeated and the obtained test results should be compared with each other.

In most mills, the existing tools and equipment used to identify physical, chemical, and technological characteristics of flour are rudimentary and not sufficient. The bread machine may be important for determining flour quality for bread making in a reasonable period of time. Furthermore, the companies that produce and market baking additives have been requesting faster and more reliable baking tests so that they can prepare an appropriate combination of additives. No relevant scientific studies have been found that compare the results of bread production using a bread machine and by standard baking.

In this study, the possibility of using automatic bread machines as quality control tools was investigated. The properties of bread made using a bread machine were compared with those of a standard free-type hearth (French) bread.

Materials and methods

In this study, 3 flour samples (Akova Flour and Feed Co., Sakarya, Turkey; Toprakcan Flour and Food Industry, Van, Turkey; and Başer Food Industry, Sakarya, Turkey); instant active dry yeast (IADY; Pak Food Production and Marketing Co., İstanbul, Turkey); a flour treatment agent including alpha amylase, vitamin C, and an emulsifier (Puratos Food Industry, İstanbul, Turkey); wheat starch (Tate and Lyle Europe NV, Aalst, Belgium); vital gluten (Meelunie America, Inc., Farmington Hills, MI, USA); and sugar and salt suitable for bread production obtained from a local market were used. To each of the 3 flour samples, 12% wheat starch and 2% vital gluten were added to adjust the protein ratio to between approximately 9.0% and 14.0%.

The following automatic bread machines were used in this study: Moulinex Home Bread (Groupe SEB İstanbul Household Appliances Trade Co., İstanbul, Turkey), Ekmatik Inox 033 (Art Kitchen Household Tools Co., İstanbul, Turkey), and Sinbo SBM-4701 (Depan Electronic Industry and Trade Company, İstanbul, Turkey). For all bread machines, the French bread program was selected.

Bread production with an automatic bread machine

Ingredients in the formula were flour (300 g, 14% moisture basis), salt (5.4 g), IADY (2.4 g), a flour treatment agent (6 g), and sugar (9 g). The total amount of flour was adjusted when starch and vital gluten were added to the formula. The amount of water to be added for optimum dough properties (500 BU) was decided based on a preliminary farinograph water absorption experiment. All baking experiments were performed in the same environment, free of airflow. First water and then flour, salt, sugar, and the flour treatment agent were added to the machines. IADY was added 1-2 min after the machine was started.

Hearth (french) bread production

Ingredients in the formula were flour (2000 g, 14% moisture basis), salt (36 g), IADY (24 g), and a flour treatment agent (40 g). The total amount of flour was adjusted when starch and vital gluten was added to the formula. Flour and treatment agents were weighed, placed in a mixer (Öztiryakiler Öm-20, İstanbul, Turkey), and blended for 15 s for a homogeneous distribution. Later, water was added. The water absorption level (%) of the flours and the total kneading duration (min) were predetermined on the basis of extensograph absorption and farinograph development time. The selected kneading speed was 100 rpm. Salt and yeast were added to the dough just 5 and 3 min before the end, respectively. The kneaded dough was rested for 30 min at 30 °C and 85%-90% relative humidity. The dough was then cut into 350-g pieces, rounded, and rested for 10 min before being formed into its final shape. The final fermentation was performed at 30 °C and 90%-95% relative humidity. The dough was removed from the fermentation cabinet and scored to give the characteristic appearance of the bread after 5 min of resting. The dough was baked at 200 °C for 20 min in a convection oven (PS5, Köseoğlu Heat Co., İstanbul, Turkey). The bread samples were cooled for 2 h, packaged in polyethylene bags, and kept at 20 °C until analysis.

Analysis of flour and bread

Ash and protein content (American Association of Cereal Chemists [AACC] methods 46-12, 08-01, and 44-15A), sedimentation value (AACC method 56-81), wet gluten and gluten index (AACC method 38-12), falling number (AACC method 56-81), and farinograph tests (water absorption, development time, stability, and degree of softening; AACC method 54-21) were determined (AACC, 1995). Bread volume (mL) was measured with a rapeseed displacement method using a loaf volumeter (Şimşek Laborteknik, Ankara, Turkey). The specific volume of bread as used bread volume to weight (mL g^{-1}) was calculated. Baking loss is expressed as a percentage of weight loss (%) after baking and was calculated by subtracting the baked bread weight from the dough weight.

Crust and crumb color parameters (L, a, and b values) of the bread were determined according to the method used by Doğan (2002). Hue (color tone) was calculated using the following formula: hue = arctan(b/a). Images of the sliced bread were captured using a flatbed scanner (HP Scan Jet 3500c, Hewlett Packard Co., Palo Alto, CA, USA) at 600 dpi resolution and analyzed as grey-level images (16 bits). Image analysis was performed using digital image analysis software 7.0 (MCID 2007). A threshold method was used for differentiating gas cells (pores) and noncells. Form factors indicating the roundness of gas cells and the ratio of gas cells to the total area (proportion) were recorded.

Bread firmness was measured in accordance with AACC (1995) standards after 3 h of baking using a TA.XTPlus texture analyzer (TA.TX2, Stable Micro Systems Ltd., Godalming, Surrey, UK) equipped with a 5-kg load cell and a 36-mm cylinder aluminum probe (P36/R). Firmness was expressed as the force (g) required for 25% compression of bread slices of 25 mm in thickness.

Statistical analysis

The flours and automatic bread-making machines were randomly coded as F_1, F_2, and F_3 and as A, B, and C, respectively. For production of hearth (french) bread, 2-way analysis of variance (ANOVA; factorial design) was applied in 3 replications. For production using the automatic bread machines, 3-way ANOVA (factorial design with 3 replications) was used on the data. Results from the 2-way ANOVA and 3-way ANOVA were evaluated independently. Fisher's least significant difference (LSD) test was used to determine significant differences. The significance level was considered to be $P < 0.05$. All statistical analyses were performed using CoStat 6.3 and StatGraphics Centurion 15.1 (Cohort 2004; StatPoint 2006).

Results

Table 1 presents the characteristics of the flour samples used in the study. A farinograph assessment of the experimental flour samples is given in Table 2. For the strong flour samples (F_1 and F_2), the addition of starch significantly decreased dough development time from 7.0 and 6.5 min to 1.8 and 1.9 min, respectively ($P < 0.05$). No significant differences were observed in development time with the addition of vital gluten to the experimental flour samples. However, the addition of vital gluten significantly increased mixing stability in the F_1 and F_3 flour samples.

Table 1. Chemical and physicochemical analysis of experimental flour samples.*

Flour	Ash (%)	Protein (%)	Sedimentation (mL)	Falling number (s)	Wet gluten (g)	Gluten index (%)
F_1	0.58	12.09	45	436	30.0	87
F_2	0.60	12.50	44	380	31.0	93
F_3	0.64	10.50	24	367	26.0	73

*Based on 14% moisture content.

Specific volume

The average specific volume of hearth bread had a range of 5.22 to 6.69 mL g^{-1} and a significant difference among the flour samples was found ($P < 0.001$). The average specific volumes of the bread samples made from F_1, F_2, and F_3 were 6.27, 5.48, and 6.43 mL g^{-1}, respectively. The difference between the average specific volumes of bread samples produced with F_1 and F_3 flour was not significant, while the specific volume of bread produced with F_2 flour was significantly lower than the others (Table 3). No significant difference exists among the flour variations or the interaction of flours and variations. In hearth bread production, the impact of change in the formula and process may not be easily observable compared to pan bread production.

The average specific volume of machine bread changed between 4.87 and 6.29 mL g^{-1} depending on the bread machine and flour variation. The specific volume of the bread was significantly affected by the machines and flour sources ($P < 0.001$), and the interactions of machine with flour and flour with protein were also significant ($P < 0.05$). The average specific volumes of bread obtained from machine C (5.71 mL g^{-1}), machine B (5.44 mL g^{-1}), machine A (5.33 mL g^{-1}), F_1 (5.99 mL g^{-1}), F_3 (5.54 mL g^{-1}), and F_2 (4.94 mL g^{-1}) are presented in Table 4 along with other results. The values of the specific volumes of bread made with both methods using different flour combinations showed similar tendencies and were affected by the flour combinations used (Table 5, Figure).

Baking loss

The baking losses of hearth bread varied between 21.78% and 23.62%, and the baking loss of bread made from F_2 was significantly lower than those of

Table 2. Farinographic analyses of experimental flour combinations.

Flour	Variations	Water absorption (%)*	Development time (min)	Stability (min)	Degree of softening (BU)
	ST	65.1b	1.8b	8.6c	48a
F_1	UT	67.4a	7.0a	11.9b	46a
	VG	67.7a	6.8a	16.9a	32b
	ST	61.4b	1.9b	13.3b	31a
F_2	UT	63.2a	6.5a	18.5a	25b
	VG	64.0a	7.2a	18.5a	30a
	ST	55.8b	1.3a	2.0c	104a
F_3	UT	57.2a	1.7a	6.8b	72b
	VG	57.6a	1.8a	8.7a	52b

*Based on 14% moisture content.
ST: starch added, UT: untreated, VG: vital gluten added.
Different small letters indicate that the farinograph attributes are significantly different from each other when compared within each group by LSD test, $P < 0.05$.

Table 3. Specific volume, baking loss, and firmness values of hearth bread samples.

	Specific volume (mL g^{-1})	Baking loss (%)	Firmness (g)
	Mean ± SE	Mean ± SE	Mean ± SE
Flour			
F_1	6.27 ± 0.15a	23.41 ± 0.36a	174.16 ± 19.4b
F_2	5.48 ± 0.15b	21.78 ± 0.36b	259.44 ± 19.4a
F_3	6.43 ± 0.15a	23.62 ± 0.36a	180.28 ± 19.4b
Variation			
ST	6.21 ± 0.15	23.27 ± 0.36	191.09 ± 19.4
UT	5.91 ± 0.15	22.69 ± 0.36	223.22 ± 19.4
VG	6.05 ± 0.15	22.85 ± 0.36	199.56 ± 19.4
Flour × variation			
F_1, ST	6.38 ± 0.26	24.22 ± 0.63	155.56 ± 33.6
F_1, UT	6.16 ± 0.26	23.22 ± 0.63	182.49 ± 33.6
F_1, VG	6.26 ± 0.26	22.80 ± 0.63	184.43 ± 33.6
F_2, ST	5.58 ± 0.26	21.62 ± 0.63	241.13 ± 33.6
F_2, UT	5.22 ± 0.26	21.56 ± 0.63	311.18 ± 33.6
F_2, VG	5.64 ± 0.26	22.16 ± 0.63	226.02 ± 33.6
F_3, ST	6.69 ± 0.26	23.98 ± 0.63	176.59 ± 33.6
F_3, UT	6.34 ± 0.26	23.29 ± 0.63	176.00 ± 33.6
F_3, VG	6.26 ± 0.26	23.57 ± 0.63	188.24 ± 33.6

ST: starch added, UT: untreated, VG: vital gluten added.
Different small letters indicate that evaluated attributes in each column are significantly different from each other when compared within each group by LSD test, $P < 0.05$.

the other flours used in the study ($P < 0.01$). Less breakage, leading to less rising during baking, was probably the reason for its lower baking loss.

The baking losses of machine bread varied between 15.39% and 17.93% depending on the machine and flour sources. The effect of machine choice (Table 4) and the effect of flour source on baking loss was significant ($P < 0.001$). As expected, baking losses in machine bread were lower than in hearth bread.

Bread firmness

The effects of flour and variations on the firmness of hearth bread samples were statistically important ($P < 0.01$). The firmness values of hearth bread made from F_1, F_2 and F_3 flours were 174.2, 259.4, and 180.3 g, respectively (Table 3). The probable reason is a big variation within each combination because of the nature of the bread.

The average firmness values of machine bread samples varied between 129.3 and 138.1 g, but no statistical difference was found among the bread machines for each flour sample in terms of firmness. The softest bread crumb (91.2 g) was obtained from F_1, the other flour samples yielded similar firmness values of 157.58 and 154.98 g, and the difference between F_2 and F_3 was not statistically significant. The results are presented in Table 4.

Form factor of crumb grain

Depending on the flour sources, the form factor, showing the roundness of the crumb grain (1 = perfectly round), varied between 0.49 and 0.52 (Table 6) and the effects of flour sources and variations on

Table 4. Specific volume, baking loss, and firmness values of machine bread samples.

	Specific volume (mL g^{-1})	Baking loss (%)	Firmness (g)
	Mean ± SE	Mean ± SE	Mean ± SE
Flour			
F_1	5.99 ± 0.04a	17.11 ± 0.17a	91.22 ± 6.33b
F_2	4.94 ± 0.04b	17.15 ± 0.17a	157.58 ± 6.33a
F_3	5.55 ± 0.04c	16.20 ± 0.17b	154.98 ± 6.33b
Variation			
ST	5.52 ± 0.04	16.91 ± 0.17	144.31 ± 6.33
UT	5.41 ± 0.04	16.61 ± 0.17	126.11 ± 6.33
VG	5.55 ± 0.04	16.95 ± 0.17	133.37 ± 6.33
Machine			
A	5.33 ± 0.04b	17.36 ± 0.17a	138.15 ± 6.33
B	5.44 ± 0.04b	16.13 ± 0.17b	129.26 ± 6.33
C	5.71 ± 0.04a	16.97 ± 0.17a	136.38 ± 6.33
Flour × variation			
F_1, ST	5.89 ± 0.08b	17.18 ± 0.29	92.08 ± 10.96
F_1, UT	5.96 ± 0.08ab	16.80 ± 0.29	89.99 ± 10.96
F_1, VG	6.14 ± 0.08a	17.34 ± 0.29	91.59 ± 10.96
F_2, ST	5.03 ± 0.08e	17.19 ± 0.29	166.70 ± 10.96
F_2, UT	4.90 ± 0.08e	17.11 ± 0.29	151.26 ± 10.96
F_2, VG	4.87 ± 0.08e	17.15 ± 0.29	154.78 ± 10.96
F_3, ST	5.65 ± 0.08c	16.36 ± 0.29	174.16 ± 10.96
F_3, UT	5.35 ± 0.08d	15.91 ± 0.29	137.07 ± 10.96
F_3, VG	5.63 ± 0.08c	16.35 ± 0.29	153.72 ± 10.96
Flour × machine			
F_1, A	5.93 ± 0.08b	17.374 ± 0.29	95.18 ± 10.96
F_1, B	5.77 ± 0.08b	16.552 ± 0.29	93.05 ± 10.96
F_1, C	6.29 ± 0.08a	17.396 ± 0.29	85.44 ± 10.96
F_2, A	4.77 ± 0.08e	17.936 ± 0.29	166.92 ± 10.96
F_2, B	5.03 ± 0.08d	16.456 ± 0.29	143.71 ± 10.96
F_2, C	5.10 ± 0.08d	17.067 ± 0.29	162.11 ± 10.96
F_3, A	5.38 ± 0.08c	16.780 ± 0.29	152.34 ± 10.96
F_3, B	5.51 ± 0.08c	15.392 ± 0.29	151.03 ± 10.96
F_3, C	5.74 ± 0.08b	16.441 ± 0.29	161.58 ± 10.96
Variation × machine			
ST, A	5.26 ± 0.08	17.20 ± 0.29	146.56 ± 10.96
ST, B	5.45 ± 0.08	16.39 ± 0.29	138.02 ± 10.96
ST, C	5.86 ± 0.08	17.14 ± 0.29	148.37 ± 10.96
UT, A	5.27 ± 0.08	17.67 ± 0.29	139.00 ± 10.96
UT, B	5.43 ± 0.08	15.51 ± 0.29	121.71 ± 10.96
UT, C	5.52 ± 0.08	16.64 ± 0.29	117.61 ± 10.96
VG, A	5.45 ± 0.08	17.22 ± 0.29	128.89 ± 10.96
VG, B	5.43 ± 0.08	16.50 ± 0.29	128.06 ± 10.96
VG, C	5.75 ± 0.08	17.12 ± 0.29	143.15 ± 10.96

ST: starch added, UT: untreated, VG: vital gluten added.
Different small letters indicate that evaluated attributes in each column are significantly different from each other when compared within each group by LSD test, $P < 0.05$.

Table 5. Comparison of bread properties by bread-making test method.

Bread property	Flour (UT)	Bread-making test method	
		Hearth bread	Automatic bread machine (mean of 3 different machines)
Specific volume (mL g$^{-1)}$	F_1	6.27 ± 0.15a	5.99 ± 0.04a
	F_2	5.48 ± 0.15b	4.94 ± 0.04b
	F_3	6.43 ± 0.15a	5.55 ± 0.04c
Baking loss (%)	F_1	23.41 ± 036a	17.11 ± 0.17a
	F_2	21.78 ± 036b	17.15 ± 0.17a
	F_3	23.62 ± 036a	16.20 ± 0.17b
Firmness (g)	F_1	174.16 ± 19.4b	91.22 ± 6.33b
	F_2	259.44 ± 19.4a	157.58 ± 6.33a
	F_3	180.28 ± 19.4b	154.98 ± 6.33b

Different small letters indicate that evaluated attributes in each column are significantly different from each other when compared within each group by LSD test, P < 0.05.

Table 6. Crumb and crust attributes of hearth bread samples.

	Crumb form factor	Crumb proportion	Crust color		Crumb color	
			(L value)	Hue	(L value)	Hue
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
Flour						
F_1	0.522 ± 0.011	0.124 ± 0.007b	33.56 ± 2.69b	1.06 ± 0.03	86.70 ± 0.34a	–0.86 ± 0.4b
F_2	0.511 ± 0.011	0.164 ± 0.007a	48.44 ± 2.69a	1.17 ± 0.03	84.50 ± 0.34c	1.55 ± 0.4a
F_3	0.488 ± 0.011	0.132 ± 0.007b	34.92 ± 2.69b	1.13 ± 0.03	85.65 ± 0.34b	0.86 ± 0.4a
Variation						
ST	0.507 ± 0.011	0.154 ± 0.007a	36.36 ± 2.69	1.09 ± 0.03	86.67 ± 0.34b	0.51 ± 0.4
UT	0.516 ± 0.011	0.152 ± 0.007a	37.63 ± 2.69	1.13 ± 0.03	85.35 ± 0.34b	0.51 ± 0.4
VG	0.499 ± 0.011	0.113 ± 0.007b	42.93 ± 2.69	1.14 ± 0.03	84.82 ± 0.34b	0.51 ± 0.4
Flour × variation						
F_1, ST	0.529 ± 0.019	0.128 ± 0.013	27.80 ± 4.67	0.94 ± 0.06	86.70 ± 0.60	–1.55 ± 0.69
F_1, UT	0.542 ± 0.019	0.134 ± 0.013	36.38 ± 4.67	1.12 ± 0.06	86.99 ± 0.60	–0.52 ± 0.69
F_1, VG	0.495 ± 0.019	0.112 ± 0.013	36.50 ± 4.67	1.11 ± 0.06	84.82 ± 0.60	–0.52 ± 0.69
F_2, ST	0.506 ± 0.019	0.179 ± 0.013	45.78 ± 4.67	1.17 ± 0.06	85.96 ± 0.60	1.55 ± 0.69
F_2, UT	0.517 ± 0.019	0.188 ± 0.013	43.64 ± 4.67	1.14 ± 0.06	84.15 ± 0.60	1.54 ± 0.69
F_2, VG	0.511 ± 0.019	0.124 ± 0.013	55.91 ± 4.67	1.20 ± 0.06	83.40 ± 0.60	1.56 ± 0.69
F_3, ST	0.485 ± 0.019	0.156 ± 0.013	35.50 ± 4.67	1.16 ± 0.06	87.35 ± 0.60	1.55 ± 0.69
F_3, UT	0.491 ± 0.019	0.136 ± 0.013	32.87 ± 4.67	1.11 ± 0.06	84.93 ± 0.60	0.52 ± 0.69
F_3, VG	0.490 ± 0.019	0.105 ± 0.013	36.38 ± 4.67	1.11 ± 0.06	84.66 ± 0.60	0.51 ± 0.69

ST: starch added, UT: untreated, VG: vital gluten added
Form factor: pore roundness; proportion: the ratio of pore to total area.
Different small letters indicate that evaluated attributes in each column are significantly different from each other when compared within each group by LSD test, P < 0.05.

Table 7. Crumb and crust attributes of machine bread samples.

	Crumb form factor	Crumb proportion	Crust color (L value)	Crust color Hue	Crumb color (L value)	Crumb color Hue
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
Flour						
F_1	0.490 ± 0.006a	0.249 ± 0.012c	77.94 ± 0.66a	1.34 ± 0.01c	82.60 ± 0.3a	–1.41 ± 0.2c
F_2	0.445 ± 0.006b	0.417 ± 0.012a	74.98 ± 0.66b	1.41 ± 0.01a	77.82 ± 0.3c	0.86 ± 0.2a
F_3	0.456 ± 0.006b	0.326 ± 0.012b	78.61 ± 0.66a	1.37 ± 0.01b	80.51 ± 0.3b	0.06 ± 0.2b
Variation						
ST	0.461 ± 0.006	0.352 ± 0.012	75.69 ± 0.66a	1.35 ± 0.01	79.71 ± 0.3b	1.18 ± 0.2
UT	0.465 ± 0.006	0.314 ± 0.012	75.16 ± 0.66b	1.35 ± 0.01	80.42 ± 0.3ab	–0.40 ± 0.2
VG	0.465 ± 0.006	0.325 ± 0.012	80.69 ± 0.66b	1.41 ± 0.01	80.81 ± 0.3a	-0.28 ± 0.2
Machine						
A	0.452 ± 0.006	0.356 ± 0.012a	75.44 ± 0.66b	1.38 ± 0.01	79.64 ± 0.3b	0.18 ± 0.2
B	0.467 ± 0.006	0.333 ± 0.012ab	80.93 ± 0.66a	1.42 ± 0.01	80.17 ± 0.3b	–0.51 ± 0.2
C	0.472 ± 0.006	0.303 ± 0.012b	75.16 ± 0.66b	1.32 ± 0.01	81.13 ± 0.3a	-0.16 ± 0.2
Flour × variation						
F_1, ST	0.453 ± 0.011	0.289 ± 0.020	83.06 ± 1.14	1.31 ± 0.02	81.19 ± 0.52	–1.54 ± 0.35c
F_1, UT	0438 ± 0.011	0.223 ± 0.020	78.50 ± 1.14	1.33 ± 0.02	77.90 ± 0.52	–1.18 ± 0.35c
F_1, VG	0.503 ± 0.011	0.234 ± 0.020	80.49 ± 1.14	1.38 ± 0.02	83.34 ± 0.52	–1.52 ± 0.35c
F_2, ST	0.464 ± 0.011	0.415 ± 0.020	75.84 ± 1.14	1.39 ± 0.02	80.80 ± 0.52	0.86 ± 0.35ab
F_2, UT	0.444 ± 0.011	0.410 ± 0.020	71.60 ± 1.14	1.39 ± 0.02	77.60 ± 0.52	1.21 ± 0.35a
F_2, VG	0.488 ± 0.011	0.426 ± 0.020	78.04 ± 1.14	1.43 ± 0.02	82.85 ± 0.52	0.52 ± 0.35ab
F_3, ST	0.451 ± 0.011	0.351 ± 0.020	76.92 ± 1.14	1.34 ± 0.02	79.55 ± 0.52	1.22 ± 0.35a
F_3, UT	0.451 ± 0.011	0.310 ± 0.020	74.84 ± 1.14	1.33 ± 0.02	77.96 ± 0.52	–1.22 ± 0.35c
F_3, VG	0.481 ± 0.011	0.317 ± 0.020	75.30 ± 1.14	1.43 ± 0.02	81.63 ± 0.52	0.18 ± 0.35b
Flour × machine						
F_1, A	0.479 ± 0.011	0.221 ± 0.020f	77.43 ± 1.14	1.32 ± 0.02	82.94 ± 0.52	–1.18 ± 0.35
F_1, B	0.482 ± 0.011	0.280 ± 0.020de	82.98 ± 1.14	1.42 ± 0.02	81.30 ± 0.52	–1.53 ± 0.35
F_1, C	0.510 ± 0.011	0.245 ± 0.020ef	73.42 ± 1.14	1.27 ± 0.02	83.57 ± 0.52	–1.53 ± 0.35
F_2, A	0.430 ± 0.011	0.478 ± 0.020a	68.66 ± 1.14	1.45 ± 0.02	76.83 ± 0.52	1.55 ± 0.35
F_2, B	0.456 ± 0.011	0.405 ± 0.020b	79.09 ± 1.14	1.41 ± 0.02	78.03 ± 0.52	0.17 ± 0.35
F_2, C	0.448 ± 0.011	0.369 ± 0.020bc	77.19 ± 1.14	1.35 ± 0.02	78.59 ± 0.52	0.86 ± 0.35
F_3, A	0.448 ± 0.011	0.369 ± 0.020bc	80.23 ± 1.14	1.36 ± 0.02	79.16 ± 0.52	0.17 ± 0.35
F_3, B	0.462 ± 0.011	0.314 ± 0.020cd	80.72 ± 1.14	1.41 ± 0.02	81.16 ± 0.52	–0.17 ± 0.35
F_3, C	0.458 ± 0.011	0.294 ± 0.020de	74.87 ± 1.14	1.33 ± 0.02	81.21 ± 0.52	0.18 ± 0.35
Variation × machine						
ST, A	0.454 ± 0.011	0.376 ± 0.020	73.31 ± 1.14	1.40 ± 0.02	79.88 ± 0.52	0.53 ± 0.35
ST, B	0.470 ± 0.011	0.350 ± 0.020	79.74 ± 1.14	1.48 ± 0.02	80.81 ± 0.52	–0.16 ± 0.35
ST, C	0.459 ± 0.011	0.329 ± 0.020	74.01 ± 1.14	1.35 ± 0.02	81.73 ± 0.52	0.17 ± 0.35
UT, A	0.451 ± 0.011	0.329 ± 0.020	74.83 ± 1.14	1.36 ± 0.02	80.27 ± 0.52	–0.17 ± 0.35
UT, B	0.476 ± 0.011	0.320 ± 0.020	77.68 ± 1.14	1.39 ± 0.02	80.04 ± 0.52	–0.51 ± 0.35
UT, C	0.469 ± 0.011	0.294 ± 0.020	72.96 ± 1.14	1.30 ± 0.02	80.93 ± 0.52	–0.50 ± 0.35
VG, A	0.451 ± 0.011	0.376 ± 0.020	73.31 ± 1.14	1.38 ± 0.02	78.78 ± 0.52	0.53 ± 0.35
VG, B	0.454 ± 0.011	0.350 ± 0.020	79.74 ± 1.14	1.37 ± 0.02	79.64 ± 0.52	–0.16 ± 0.35
VG, C	0.489 ± 0.011	0.329 ± 0.020	74.01 ± 1.14	1.29 ± 0.02	80.71 ± 0.52	0.17 ± 0.35

ST: starch added, UT: untreated, VG: vital gluten added

Different small letters indicate that evaluated attributes in each column are significantly different from each other when compared within each group by LSD test, $P < 0.05$.

the form factor of hearth bread crumb grain were insignificant ($P > 0.05$).

The highest form factor was obtained from F_1 and the effects of flour sources on the form factor of machine bread crumb grain were significant ($P < 0.001$). In both baking methods, the average and highest form factors were obtained from F_1 (0.52 for hearth bread and 0.49 for machine bread). The results are shown in Table 7.

Grain-to-total area ratio (proportion)

The flour source and variations significantly affected the proportions of hearth bread ($P < 0.01$). The highest proportion was observed when F_2 was used (Table 6). The interaction between flour and protein was not significant ($P > 0.05$). Higher proportions indicated an increase in crumb gas cells in the evaluated crumb region.

The effects of flour sources and machines on proportion are shown in Table 7. The average proportion values of machine bread made from F_1, F_2, and F_3 were 0.249, 0.417, and 0.326, respectively, and were significantly different from each other ($P < 0.001$).

Crust color

The crust color of bread affects consumer preference at the point of purchase and serves as an indicator of well-baked bread (Zanoni et al. 1995). The average L and hue values of crust color of bread samples obtained from different flour sources and variations are given in Tables 6 and 7.

The L values of hearth bread crust varied between 33.6 and 48.4, and a significant difference was found only among flour sources. Hue values of crust were not significantly affected by flour sources and variations.

The crust L and hue values of machine bread were also significantly affected by flour source, variation, and the machine used in the experiment ($P < 0.001$). The average L values of machine bread ranged between 75.16 and 80.93. The highest L value, the lightest color, was obtained with machine B (Table 7). The average L values of bread made from each flour source were different from each other ($P < 0.05$), but the interval was narrow, ranging from 74.98 to 78.61. Hue values were significantly affected by flour sources, variations, and bread machines ($P < 0.001$).

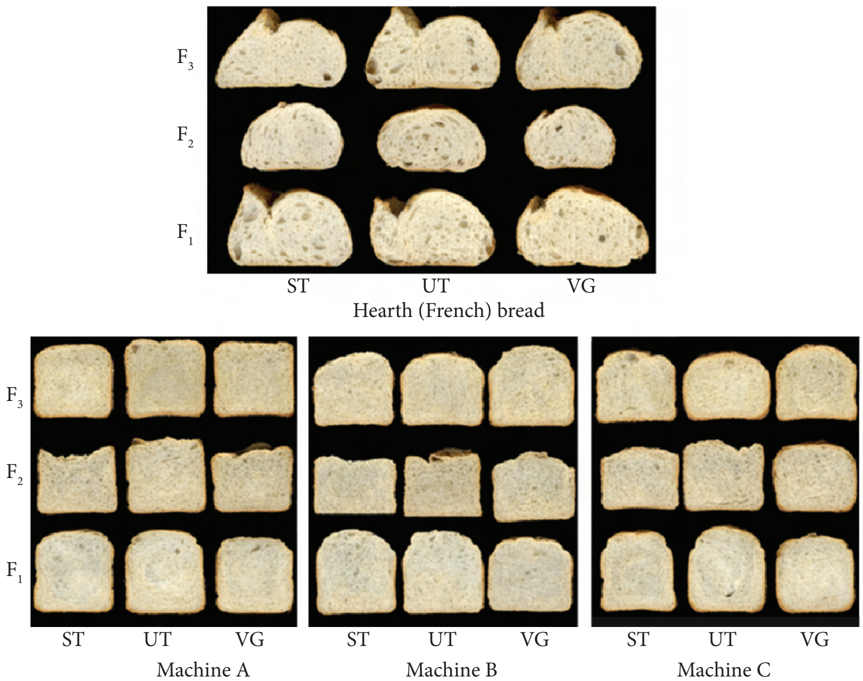

Figure. Cross cut of experimental bread samples (ST: starch added, UT: untreated, VG: vital gluten added).

Crumb color

The crumb L and hue values of hearth bread were significantly affected by flour source and variation ($P < 0.001$). The average L values of hearth bread ranged between 84.50 and 86.70 (Tables 6 and 7). Crumb color was affected by the addition of starch and vital gluten to the flours. The flour source also significantly affected the crumb hue values ($P < 0.01$)

Although the values are very close to each other (Table 7), the crumb L values of machine bread were significantly affected by all flour sources ($P < 0.001$), machines ($P < 0.01$), machine and flour interactions ($P < 0.05$), and the interaction of machine, flour, and variations ($P < 0.05$), as shown in the Figure. Crumb hue values were also significantly affected by flour source ($P < 0.001$), flour and protein interactions ($P < 0.001$), and machine, flour, and variations interactions ($P < 0.05$).

Discussion

The addition of 12% starch to the experimental flour samples weakened the gluten strength so that the mixing stability decreased, whereas adding 2% extra vital gluten increased the stability.

One of the most important criteria used in determining the quality of flour is to determine the volume of the bread. We observed in this study that a higher protein content yielded either tight dough or resulted in less breakage or shredding at the point of scoring, yielding lower volume and inferior crumb features. A hearth bread process is more difficult than pan bread production; therefore, sometimes it is difficult to see the effect of small variations in protein content.

Because bread machines have better control of the baking process, the effects of flour combination on bread volume were observable. The significant interactions between machine and flour indicate that the performances of bread machines differ depending on their design and programming. However, all machines showed similar tendencies in relation to the flour source used in the experiment.

The relationship between the protein content of flour and the volume of bread has been known for many years and is used in quality bread production with new wheat varieties (Unal and Boyacioglu 1984). Færgestad et al. (1999) prepared 12 mixtures from 4 different flour samples in variations of 10.2%-14.3% and a very important relationship between bread volume and variation was found. More than the total variation, the importance of gluten quality on bread volume was highlighted in this study. The ideal gluten quantity and quality is not the same in the production of hearth, whole wheat, and pan breads.

Baking losses changed between 21.78% and 23.62% for hearth bread, and between 15.39% and 17.93% for machine bread. The type of baking pans and machine design contributed to the alteration in baking loss. In comparison to hearth bread, baking loss in machine bread is less than about 5%-7% as a consequence of the controlled baking in bread machines, and variation in baking loss between the machines was 1%-2% (Table 4).

Even though the proportion of crumb with gas cells was different for hearth and machine breads, the magnitude and direction of difference for the ratio were similar. Coalescence of gas cells and bigger grain formation in hearth bread probably caused a lower proportion rate. Crumb grain structure and grain distribution throughout the bread is important for sensory evaluation. Both loaf volume and crumb grain quality are equally important for the overall quality. For crumb grain evaluation, 2-dimensional digital image analyses, crumb grain size and distribution analyses, magnetic resonance imaging, and Monte Carlo simulation techniques may be also used (Regier et al. 2007).

The crust L values of bread made from different flours in both methods were significantly different. The temperature of the baking chamber in the bread machine was about 70 °C lower than the oven temperature and the moisture removal rate was also lower due to a closed top cover. Therefore, the top crust color of machine bread was lighter than that of hearth bread.

Even though no significant differences exist among the hearth bread data, the obtained average data are similar to those of machine breads. The oven temperature during bread machine production is completely controlled. The smaller color differences between assessments make the difference important due to a smaller standard error of average results of color L and hue values from bread machines.

The effect of protein levels (variation) on the firmness values of both hearth and machine bread was statistically insignificant ($P > 0.05$). The flour sources significantly affected crumb firmness in both baking methods, with F_1 yielding the softest crumb and F_2 yielding the hardest crumb. Because of the nature of hearth bread, the compressibility values of hearth bread were higher than those of machine bread, as seen in most pan breads due to variations in baking methods (Tables 3 and 4).

The crumb L values in both hearth and machine bread were the highest for F_1 and the lowest for F_2, with F_3 in the middle, and we observed the effect of flour source and variations in both baking methods. The effect of flour sources on crumb hue values was observed to have similar tendencies in both methods. However, the level of significance was not the same due to the difference of baking methods. Hue value provides information about the intensity of the color. A lower hue value means the color is darker.

One important factor is that the specific volumes of breads produced by both methods changed depending on flour source. The amount of protein significantly affected the machine bread volume, but changing the protein level (variation) did not affect the volume of the hearth bread. The bread machine production was more controlled. Changes in the quantity of protein were reflected in the specific volumes of the bread. Furthermore, the significance of bread machine and flour source interaction indicates that the performances of the bread machines are not the same. This difference in performance may be caused by the heterogeneity of the machines' baking programs. In addition, crumb firmness and crust and crumb color of bread made with both methods were significantly affected by flour sources in the same way but not at the same level of significance. Considering the repeatability of the results, it can be concluded that the bread-making potential of flour can be achieved by using a bread machine. The performance of bakery additives can also be assessed with a bread machine without professional experience in the field.

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