Effect of Baking Absorption on Bread Yield, Crumb Moisture, and Crumb Water Activity[1]

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ABSTRACT

Three cultivars of hard red spring wheat with identical protein contents were milled on a Buhler mill. The farinograph absorptions of the flours at the 500-BU line varied. Bread was baked from this flour using both the straight dough and sponge and dough methods at five absorption levels with each system. From the two higher absorption flours, bread yield loss was greater with the sponge and dough procedure than with the straight dough method. As the absorption levels in the baking formula increased, an increased bread yield loss was noted. Total bread weights from the high-absorption flours were greater than weights from the low-absorption flours. Bread crumb moisture, as determined by the two-step oven method, decreased over a four-day storage period. Water activity values for the bread crumb ranged from 0.995 to 0.975 in the study. One of the cultivars was further milled to produce additional levels of starch damage for different absorptions. Similar results were obtained for bread crumb moisture and water activity for these samples and for the three cultivars used initially.

Flours that require high absorption levels to produce doughs of a certain consistency are desirable for bread baking. The amount of dough produced from a fixed amount of flour increases with an increase in water content or absorption. This is an important factor from an economic standpoint. Because water is one of the least expensive ingredients, bakers can increase bread yield by choosing a flour with a higher absorption flour and, thus, increase profits. The bread quality desired and the dough machinability also would be factors in the type of flour required by the baker. Although dough yield increases as absorption increases, a corresponding increase in bread yield may or may not occur. Greater water loss during the baking stage would necessitate using more dough weight for a resultant fixed bread weight. Tipples and Kilborn (1968) noted that farinograph absorption increased almost linearly with an increase in starch and that bread yield increased proportionally with the baking absorption. Farrand (1972) stated that satisfactory bread could be made from pin-milled flour over a range of 18–30 Farrand starch damage units using a straight dough method.

The role of water during the bread-staling process was examined by Pisesookbunterng and D'Appolonia (1983). It was noted that in bread not decrusted, a measurable moisture loss in the crumb occurred because of the migration of moisture from the crumb to the crust. Decrusted bread crumb showed a constant crumb moisture during four days of storage. Czuchajowska et al (1989) stated that there were large differences found in the bread crumb moistures in bread baked with various baking absorption levels. In addition, they found little change in water activity between the 1- and 24-hr-old bread crumb. The functional availability of water in cereal foods and the subsequent presence of strongly bound, unavailable water was researched by Multon et al (1980). The relationship between water activity of a cereal food and its moisture content was defined using sorption isotherm curves. Rogers et al (1988) stated that bread moisture content influenced the firming rate and starch retrogradation. Firming rate was retarded in the higher moisture bread in the study. They further noted that the fastest firming bread, which had the lowest moisture, also had the slowest starch retrogradation, similar to the effect found in starch gels. Zeleznak and Hoseney (1986) also noted that the retrogradation of wheat starch gels was affected by the amount of water present during bread storage and that starch recrystallization of starch gel and bread was affected by the moisture content.

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The purpose of this study was to determine the effect of adding different amounts of water to different flours and to ascertain the economic advantage in terms of the number of loaves of bread produced. Because bread is sold by weight, the study compared the loss in the dough weight after mixing to the final baked loaf. To determine the advantage of high-absorption flours in baking, bread yield loss was examined as it related to the baking absorption required by the flours. A straight dough and sponge and dough methods were used. Total bread yield loss was determined from the weight of dough immediately after mixing compared to the final bread weight. Varying levels of water from the optimum baking absorption also were added to determine the change in the yield loss. The relationship of water activity to total moisture content in the bread crumb was examined immediately after baking and during storage.

MATERIALS AND METHODS

Three hard red spring wheat cultivars were selected to obtain Buhler-milled flours (Buhler Miag, Minneapolis, MN) of varying water absorption but the same flour protein (15.6% dry-moisture basis [dmb]) and medium-strong to strong farinograph properties. The optimum baking absorption and mix time were estimated on the basis of farinogram curves and by an experienced experimental baker's estimation of dough machinability.

Two baking methods were used. The first was a straight dough procedure that used a 3-hr fermentation with two punches at 95 and 145 min after mixing. The breadmaking formula was flour, 100%; yeast, 3%; salt, 2%; sugar, 5%, shortening, 3%; and water (variable). The second baking method was a sponge and dough procedure in which the sponge was fermented for 4 hr. The sponge contained 70% of the flour, 2% yeast, 0.5% yeast food, and 70% of the water. The remaining ingredients (flour, 30%; salt, 2%; sugar, 5%; shortening, 3%; and water, which was 30% of the total water used) were added at the dough stage and mixed to optimum development. The dough was returned to the fermentation cabinet and allowed to rest for 40 min before dividing, rounding, and panning.

The optimum absorption for both baking procedures was determined as 3.5% less than the farinograph absorption. Adjustments were made in the baking formula to include ±4.0 or ±2.0% water from the optimum absorption. All doughs were mixed in batch form on a Hobart D 300-T mixer (Hobart Corporation, Troy, OH) with enough flour to produce a minimum of five 500-g loaves. A minimum of two batches were mixed for each flour formulation except for one batch of the low-absorption Marshall flour. A National fermentation (National Manufacturing Co., Lincoln, NE) cabinet held at 30 ± 1°C with 80 ± 5% rh was used for the fermentation periods. All batches were divided into 500-g pieces, rounded, allowed to rest 10 min, molded using a Moline experimental molder (Moline Co., Duluth, MN), and placed into pans. Panned doughs were proofed for 55 min in a Despatch experimental proofing cabinet (Despatch Oven Co., Minneapolis, MN) at 43 ± 1°C with a relative humidity of 90 ± 5%. Baking was done in a Despatch rotating oven for 25 min at 204°C.

Dough yield loss was determined by comparing batch dough weight after mixing with dough weight before the dough was divided into 500-g pieces. In addition, yield loss also was determined by comparing dough weight (500 g) at dividing with the dough weight before placing in the oven and with the final bread weight. Bread yield losses reported in this study include the entire baking process from the weight of the dough at mixing to final bread weight. The loaves were weighed 1 hr after removal from the oven, and loaf volume was determined by the rapeseed displacement method.

Bread crumb moisture was determined according to AACC (1983) procedure 44-15A. Water activity in the bread crumb was determined using the microcrystalline cellulose method proposed by Vos and Labuza (1974). This procedure involved a standard sorption isotherm curve for the microcrystalline cellulose established using standard sulfuric acid solutions. Fifty grams of bread crumb was placed in a desiccator with weighing bottles of dry microcrystalline cellulose for 24 hr. The water activity of the crumb was determined by measuring the weight gain of the microcrystalline cellulose and referring to the standard curve. Bread crumb moisture and water activity were done 2 hr after removal from the oven using the following procedure. The bread was sliced and 10 g of bread crumb was removed for bread crumb moisture determination by cutting a central plug from one center slice and from a slice off each end of the loaf. Fifty grams of crumb were obtained in a similar fashion for water activity determination.

TABLE I
Farinograph Data for All Flours

Variety	Absorption[a] (%)	Peak Time (min)	Stability (min)	MTI[b] (BU)
Buhler milled				
Butte 86	72.6	9.5	9.0	20
Len	69.8	11.5	14.0	20
Marshall	60.4	7.5	10.5	20
Miag milled				
Marshall a	57.9	8.0	12.0	30
b	60.2	8.0	11.0	30

[a] Absorption at 500 BU, 14.0% moisture basis.
[b] Mixing tolerance index.

The remaining loaves were sliced, placed in polyethylene bags, and kept at room temperature, 24 ± 2°C. Bread crumb moisture and water activity were determined two and four days after removal from the oven.

In one experiment, the cultivar that produced the lowest water absorption flour was milled on a Miag mill (Buhler Miag), and an aliquot of this flour was further damaged using the reduction rolls of an Allis mill (Allis-Chalmers Manufacturing Co., Milwaukee, WI) to produce flours with starch damage values of 16.8 and 24.3%. This resulted in two flours with different optimum baking absorption requirements. A minimum of two batches was made, resulting in three 500-g loaves per batch. Starch damage was measured according to the method proposed by Farrand (1964).

Farinograms were determined with a 50-g bowl using AACC (1983) procedure 54-21. Amylographs were performed on 100 g of flour (14% moisture basis) in 460 ml of water containing 46 ml of amylograph buffer (AACC 1983, method 22-10). Flour moisture, ash, and protein content were measured by AACC (1983) methods 44-15A, 08-01, and 46-11, respectively.

Analytical determinations were performed at least twice and all results were averaged unless otherwise indicated on the table. The results were subjected to analysis of variance and evaluated by Duncan's multiple range test. Statistically significant differences at the 5% level are presented.

RESULTS AND DISCUSSION

The ash contents of the Buhler-milled Butte 86, Len, and Marshall cultivars were 0.48, 0.50, and 0.51 dmb, respectively. Protein content on a dry-moisture basis for all three flours was 15.6%. Starch damage for the Butte 86, Len, and Marshall flours was 49.6, 60.4, and 39.8 Farrand units, respectively. Ash and protein content of the original Miag-milled Marshall flour and the second Marshall flour further starch damaged on the reduction rolls of the Allis mill were 0.42 and 15.7% dmb, respectively. Starch damage for these two flours were 16.8 and 24.3 Farrand units, respectively. Farinograph data of the five flours are shown in Table I and indicated medium-strong to strong mixing properties.

Bread weights and volumes for the Buhler-milled Butte 86, Len, and Marshall flours are shown in Table II. All three varieties, except Marshall using the sponge and dough method, showed a decrease in final bread weight as more water was added to the formula. Butte 86, Marshall, and, to a lesser extent, Len

TABLE II
Weight and Volume of Bread Loaves of the Buhler-Milled Flours Obtained from 500-g Flour Doughs Baked with Different Absorption Levels

Variety	Baking Absorption (%)	Weight,[a] g		Volume,[a] cm^3	
		Straight Dough	Sponge and Dough	Straight Dough	Sponge and Dough
Butte 86	+4% (73.1)	419.3 c[b]	412.8 c	2,275 ab	2,539 a
	+2% (71.1)	422.6 bc	417.0 b	2,319 a	2,441 a
	Optimum (69.1)	423.0 b	417.4 b	2,231 bc	2,469 a
	−2% (67.1)	425.3 ab	418.5 b	2,203 c	2,469 a
	−4% (65.1)	427.6 a	422.2 a	2,117 d	2,525 a
SD		0.33–1.97	0.63–4.56	12.5–66.1	0.0–75.0
Len	+4% (70.3)	423.8 c	422.7 b	2,247 a	2,178 b
	+2% (68.3)	424.7 bc	424.2 ab	2,200 b	2,292 a
	Optimum (66.3)	425.8 b	424.5 ab	2,200 b	2,214 ab
	−2% (64.3)	426.2 b	425.9 a	2,186 b	2,240 ab
	−4% (62.3)	431.3 a	425.7 a	2,169 b	2,240 ab
SD		0.44–1.61	1.10–3.70	24.3–57.7	28.5–62.5
Marshall	+4% (61.9)	422.0 c	436.5 a	2,475 a	2,290 a
	+2% (59.9)	421.4 c	434.8 a	2,519 a	2,345 a
	Optimum (57.9)	424.2 c	429.5 b	2,400 b	2,385 a
	−2% (55.9)	427.1 b	429.1 b	2,270 c	2,462 a
	−4% (53.9)	433.0 a	431.2 b	2,275 c	2,281 a
SD		0.92–2.38	1.24–1.97	20.41–46.8	23.9–248.4

[a] One hour after baking.
[b] Values followed by different letters indicate statistically significant differences at the 5% level.

TABLE III
Weight and Volume of Bread Loaves of the Marshall Flours with Different Starch Damage Levels Obtained from 500-g Flour Doughs Baked with Different Absorption Levels

Variety	Baking Absorption (%)	Weight,[a] g		Volume,[a] cm^3	
		Straight Dough	Sponge and Dough	Straight Dough	Sponge and Dough
Marshall, 24.3[b]	+4% (60.7)	418.4 c[c]	421.6 b	2,522 ab	2,719 a
	+2% (58.7)	421.6 bc	422.0 b	2,606 a	2,669 a
	Optimum (56.7)	423.2 b	424.7 b	2,600 a	2,650 a
	−2% (54.7)	426.9 a	428.5 a	2,556 ab	2,359 b
	−4% (52.7)	430.1 a	429.9 a	2,478 b	2,278 b
SD		0.54–2.53	0.29–2.76	0.0–68.8	23.9–77.4
Marshall, 16.8[b]	+4% (58.4)	422.0 d	424.8 c	2,534 a	2,643 ab
	+2% (56.4)	425.4 c	426.9 bc	2,534 a	2,659 a
	Optimum (54.4)	428.7 b	427.5 bc	2,522 ab	2,625 ab
	−2% (52.4)	431.4 b	429.6 b	2,438 b	2,572 b
	−4% (50.4)	435.3 a	435.8 a	2,316 c	2,344 c
SD		0.57–3.08	0.24–1.84	12.5–85.1	14.4–73.6

[a] One hour after baking.
[b] Percent starch damage in Farrand units determined using Farrand method.
[c] Values followed by different letters indicate statistically significant differences at the 5% level.

TABLE IV
Percent Bread Yield Loss in Weight of Dough During the Entire Baking Process from Doughs of the Buhler-Milled Flours that Varied in Optimum Baking Absorption and Baked with Different Absorption Levels

Variety	Baking Absorption (%)	Loss, %	
		Straight Dough	Sponge and Dough
Butte 86	+4% (73.1)	17.23 a[a]	18.78 a
	+2% (71.1)	16.58 ab	17.98 b
	Optimum (69.1)	16.39 b	17.88 b
	−2% (67.1)	15.96 bc	17.52 b
	−4% (65.1)	15.37 c	16.88 b
SD		0.061–0.405	0.127–1.010
Len	+4% (70.3)	16.71 a[a]	16.97 a
	+2% (68.3)	16.53 ab	16.39 b
	Optimum (66.3)	15.80 b	16.40 b
	−2% (64.3)	15.69 b	16.04 b
	−4% (62.3)	14.55 c	16.12 b
SD		0.085–0.324	0.218–0.734
Marshall	+4% (61.9)	16.71 a[a]	13.62 a
	+2% (59.9)	16.71 a	13.91 a
	Optimum (57.9)	15.99 b	14.97 a
	−2% (55.9)	15.31 c	14.99 a
	−4% (53.9)	14.04 d	14.53 a
SD		0.186–0.480	0.255–0.397

[a] Values followed by different letters indicate statistically significant differences at the 5% level.

TABLE V
Percent Loss in Weight of Dough During the Entire Baking Process from Doughs that Varied in Starch Damage and Baked with Different Absorption Levels

Variety	Baking Absorption (%)	Loss, %	
		Straight Dough	Sponge and Dough
Marshall, 24.3[a]	+4% (60.7)	17.49 a[b]	16.49 a
	+2% (58.7)	16.71 b	16.49 a
	Optimum (56.7)	16.22 bc	15.82 ab
	−2% (54.7)	15.46 c	15.06 bc
	−4% (52.7)	14.66 d	14.67 c
SD		0.104–0.452	0.057–0.565
Marshall, 16.8[a]	+4% (58.4)	16.76 a	15.74 a
	+2% (56.4)	15.87 a	15.34 ab
	Optimum (54.4)	15.10 b	15.14 ab
	−2% (52.4)	14.57 b	14.69 b
	−4% (50.4)	13.67 c	13.48 c
SD		0.111–0.624	0.053–0.358

[a] Percent starch damage in Farrand units determined using Farrand method.
[b] Values followed by different letters indicate statistically significant differences at the 5% level.

showed an increase in volume as more water was added to the baking formula when the straight dough method was used. The sponge and dough method did not show this increase.

Bread weights and volumes for the Miag-milled Marshall flours with two differing levels in starch damage are shown in Table III. Both flours showed a decrease in final bread weight and a general increase in bread volume as more water was added to the formula. The bread weights are based on 500-g dough pieces. The final bread weights indicate that an increase in the water content in the formulation results in less bread weight per unit of dough.

Table IV summarizes the results of the loss in dough weights from mixing to the final bread weight for the Buhler-milled flour cultivars with varied optimum baking absorption levels. The three different flours showed an increase in percent yield loss as more water was added to the baking formula when the straight dough method was used. When the sponge and dough method was used, Butte 86 and Len show an increase in bread yield loss only at the highest absorption level. When the total yield losses for Butte 86, Len, and Marshall were compared using Duncan's multiple range test, the sponge and dough method showed a significantly different mean yield loss (16.48%) than the straight dough method (15.93%). The total bread yield loss for Butte 86, Len, and Marshall, with means of 17.0, 16.0, and 15.0%, respectively, would indicate statistically significant differences at the 5% level.

The losses of weight from mixing to the final bread weight for bread made from the Miag-milled Marshall flours with different levels of starch damage are shown in Table V. Both baking methods showed an increase in percent yield loss as more water was added to the baking formula. When the two baking methods were compared using Duncan's multiple range test, the mean yield loss (15.33%) was the same for both methods. The Marshall flours with 24.3 and 16.8 Farrand starch damage units had a mean yield losses of 15.9 and 15.0%, respectively, and were significantly different at the 5% level. Tables IV and V indicate that when the loss of dough weight from mixing to panning also was included in the percent bread yield loss, there was a greater yield loss as more water was added to the baking formula. If the bread yield losses of the three cultivars used in the study were calculated with the mean baking absorptions, the amount of ingredients required to produce 100 456-g (1-lb) loaves could be determined. Table VI summarizes these results. The calculations indicate that a higher absorption flour would require less flour and other ingredients, excluding water, to produce the same amount of loaves as a lower absorption flour.

The moisture contents present in the bread crumb baked from the Buhler-milled Butte 86, Len, and Marshall flours are shown in Table VII. In general, there was an increase in crumb moisture content as more water was added to the baking formula, except for the Butte 86 baked with the straight dough method and measured after 2 hr. The standard deviation for this set of samples also was high. Bread from the Marshall flour also showed an increase in crumb moisture content as more water was added to the baking formula. However, no statistics were possible as it was only baked once. The moisture content of the bread made with the Marshall samples with different starch damage levels (Table VIII) also was shown to increase as absorption in the baking formula increased. In Tables VII and VIII, there is a decrease over time in the crumb moisture content during the four-day storage period.

The water activity of the bread crumb from the Buhler-milled Butte 86, Len, and Marshall flours is summarized in Table IX. The Len flour, using the straight dough baking method, showed some statistical variation in water activity on the bread crumb after two days of storage. However, the range in water activity

TABLE VI
Cultivar Effect on Bread Yield at Various Absorptions

Variety	Mean Baking Absorption[a] (%)	Yield Loss (%)	Dough Weight[b] (kg)	Dough Weight (lb)	Water[c] (kg)	Water (lb)	Flour[d] (kg)	Flour (lb)
Butte 86	69.1	17.0 a[e]	53.35	117	21.80	47.81	31.55	69.19
Len	66.3	16.0 b	52.90	116	21.09	46.25	31.81	69.75
Marshall	57.9	15.0 c	52.44	115	19.23	42.17	33.21	72.83

[a] Includes both baking methods and all baking absorptions used.
[b] Dough weight required to produce 100 456-g (1-lb) loaves of bread.
[c] Water required to produce 100 456-g (1-lb) loaves of bread.
[d] Flour and other ingredients (constant) required to produce 100 456-g (1-lb) loaves of bread.
[e] Values followed by different letters indicate statistically significant differences at the 5% level.

TABLE VII
Moisture (%) Content in Crumb of Bread Baked From Flours that Varied in Optimum Baking Absorption and Baked with Different Absorption Levels

Variety	Baking Absorption (%)	Straight Dough[a]			Sponge and Dough[a]		
		After 2 Hr	After 2 Days	After 4 Days	After 2 Hr	After 2 Days	After 4 Days
Butte 86	+4% (73.1)	51.2 a[b]	51.3 a	50.0 a	51.1 a	51.2 a	50.0 a
	+2% (71.1)	50.5 a	50.7 ab	50.0 a	50.2 b	50.4 ab	49.8 a
	Optimum (69.1)	49.8 a	50.0 bc	49.0 ab	49.5 c	49.4 bc	48.5 ab
	−2% (67.1)	49.4 a	49.4 c	48.7 ab	49.4 c	48.8 cd	48.7 ab
	−4% (65.1)	49.0 a	49.0 c	47.8 b	48.2 d	47.8 d	47.7 b
SD		0.92–1.48	0.14–0.71	0.07–0.85	0.0–0.35	0.07–0.71	0.07–0.85
Len	+4% (70.3)	50.0 a	49.6 a	49.2 a	50.2 a	49.8 a	49.6 a
	+2% (68.3)	49.4 a	49.4 a	48.2 b	50.0 a	49.4 ab	49.1
	Optimum (66.3)	48.2 c	48.5 ab	47.5 bc	48.8 b	48.8 b	48.2 c
	−2% (64.3)	47.8 c	47.5 ab	46.9 cd	48.2 bc	48.0 c	47.6 d
	−4% (62.3)	47.2 d	46.6 b	46.4 d	47.4 c	47.1 d	47.0 e
SD		0.07–0.28	0.71–1.06	0.0–0.64	0.0–0.56	0.07–0.35	0.0–0.28
Marshall[c]	+4% (61.9)	47.2	47.0	45.9	47.3	47.4	46.8
	+2% (59.9)	46.7	46.2	45.7	46.7	46.7	46.0
	Optimum (57.9)	45.7	45.1	44.5	45.6	45.9	45.2
	−2% (55.9)	45.3	45.2	44.7	45.2	45.0	44.3
	−4% (53.9)	44.4	44.4	43.8	44.2	44.3	43.2

[a] Moistures done by two-step air oven method, done after removal from the oven at the times indicated.
[b] Values followed by different letters indicate statistically significant differences at the 5% level.
[c] Standard deviation not applicable. Marshall was baked only once and moisture determination was done only once for each observation listed.

TABLE VIII
Moisture (%) Content in Crumb of Bread From Dough that Varied in Starch Damage and Baked with Different Absorption Levels

Variety	Baking Absorption (%)	Straight Dough[a]			Sponge and Dough[a]		
		After 2 Hr	After 2 Days	After 4 Days	After 2 Hr	After 2 Days	After 4 Days
Marshall 24.3[b]	+4% (60.7)	48.6 a[c]	48.4 a	47.0 a	47.8 a	47.5 a	45.8 a
	+2% (58.7)	48.1 ab	47.6 b	46.1 a	46.9 ab	46.8 ab	45.6 a
	Optimum (56.7)	46.8 bc	46.4 c	44.5 b	46.3 ab	45.8 bc	44.6 ab
	−2% (54.7)	46.4 cd	46.2 c	44.2 b	45.9 ab	45.4 bc	44.2 ab
	−4% (52.7)	45.4 d	45.5 d	43.6 b	44.9 b	44.7 c	43.0 b
SD		0.14–0.92	0.07–0.35	0.14–0.85	0.85–1.13	0.35–0.99	0.35–1.20
Marshall, 16.8	+4% (58.4)	48.0 a	47.4 a	46.6 a	47.6 a	46.4 a	45.8 a
	+2% (56.4)	47.6 ab	46.8 b	46.0 a	46.9 a	46.3 a	45.2 a
	Optimum (54.4)	46.4 bc	45.6 c	44.6 b	45.7 b	44.9 ab	43.8 b
	−2% (52.4)	45.6 cd	45.0 d	44.0 b	45.0 bc	44.2 ab	43.6 b
	−4% (50.4)	44.4 d	44.2 e	43.0 c	44.4 c	43.6 b	42.2 c
SD		0.07–1.06	0.0–0.28	0.07–0.56	0.00–0.71	0.71–0.92	0.07–0.64

[a] Moistures done by two-step air oven method, done after removal from the oven at the times indicated.
[b] Percent starch damage in Farrand units determined using Farrand method.
[c] Values followed by different letters indicate statistically significant differences at the 5% level.

TABLE IX
Water Activity (a_w) in Crumb of Bread Baked from Flours That Varied in Optimum Baking Absorption and Baked With Different Absorption Levels

Variety	Baking Absorption (%)	Straight Dough[a] (a_W) After 2 Hr	After 2 Days	After 4 Days	Sponge and Dough[a] (a_W) After 2 Hr	After 2 Days	After 4 Days
Butte 86	+4% (73.1)	0.990 a[b]	0.995 a	0.994 a	0.995 a	0.995 a	0.995 a
	+2% (71.1)	0.995 a	0.995 a	0.995 a	0.995 a	0.994 a	0.995 a
	Optimum (69.1)	0.991 a	0.995 a	0.991 a	0.995 a	0.992 a	0.987 a
	−2% (67.1)	0.986 a	0.995 a	0.995 a	0.995 a	0.995 a	0.988 a
	−4% (65.1)	0.984 a	0.995 a	0.994 a	0.995 a	0.995 a	0.989 a
SD		0.0–0.0156	0.0	0.0–0.0056	0.0	0.0–0.035	0.0–0.0106
Len	+4% (70.3)	0.979 a	0.992 ab	0.995 a	0.988 a	0.995 a	0.995 a
	+2% (68.3)	0.995 a	0.995 a	0.995 a	0.992 a	0.995 a	0.995 a
	Optimum (66.3)	0.992 a	0.986 b	0.995 a	0.983 a	0.995 a	0.995 a
	−2% (64.3)	0.982 a	0.989 ab	0.994 a	0.981 a	0.986 b	0.986 b
	−4% (62.3)	0.995 a	0.987 b	0.988 a	0.992 a	0.995 a	0.995 a
SD		0.0–0.0155	0.0–0.0049	0.0–0.0106	0.0035–0.0162	0.0–0.0007	0.0–0.0035
Marshall[c]	+4% (61.9)	0.990	0.995	0.980	0.995	0.992	0.995
	+2% (59.9)	0.987	0.995	0.985	0.995	0.995	0.995
	Optimum (57.9)	0.995	0.980	0.988	0.995	0.995	0.995
	−2% (55.9)	0.995	0.995	0.995	0.977	0.995	0.995
	−4% (53.9)	0.975	0.995	0.975	0.995	0.980	0.995

[a] Water activity measured using microcrystalline cellulose method.
[b] Values followed by different letters indicate statistically significant differences at the 5% level.
[c] Marshall was baked only once.

TABLE X
Water Activity (a_w) in Crumb of Bread Baked from Doughs That Varied Starch Damage and Baked with Different Absorption Levels

Variety	Baking Absorption (%)	Straight Dough[a] (a_W) After 2 Hr	After 2 Days	After 4 Days	Sponge and Dough[a] (a_W) After 2 Hr	After 2 Days	After 4 Days
Marshall 24.3[b]	+4% (60.7)	0.995 a[c]	0.994 a	0.995 a	0.995 a	0.995 a	0.995 a
	+2% (58.7)	0.986 b	0.980 b	0.990 a	0.995 a	0.980 b	0.975 a
	Optimum (56.7)	0.995 a	0.995 a	0.995 a	0.995 a	0.995 a	0.995 a
	−2% (54.7)	0.994 a	0.995 a	0.995 a	0.995 a	0.995 a	0.995 a
	−4% (52.7)	0.995 a	0.995 a	0.995 a	0.995 a	0.970 c	0.995 a
SD		0.0–0.0057	0.0–0.0035	0.0–0.0071	0.0	0.0–0.0042	0.0–0.0035
Marshall, 16.8	+4% (58.4)	0.986 a	0.990 a	0.982 a	0.995 a	0.982 a	0.995 a
	+2% (56.4)	0.989 a	0.995 a	0.993 a	0.988 a	0.992 a	0.995 a
	Optimum (54.4)	0.995 a	0.995 a	0.994 a	0.995 a	0.995 a	0.995 a
	−2% (52.4)	0.986 a	0.988 a	0.985 a	0.995 a	0.991 a	0.995 a
	−4% (50.4)	0.995 a	0.995 a	0.995 a	0.995 a	0.995 a	0.995 a
SD		0.0–0.0120	0.0–0.0091	0.0–0.0141	0.0–0.0106	0.0–0.0177	0.0

[a] Water activity measured using microcrystalline cellulose method.
[b] Percent starch damage in Farrand units determined using Farrand method.
[c] Values followed by different letters indicate statistically significant differences at the 5% level.

values was very small (0.995–0.975) during the four-day storage period for all samples presented in Table IX. The water activity of the bread made from the Marshall flours with different levels of starch damage is presented in Table X. The water activity range for these samples was 0.995–0.970. Statistically significant differences at the 5% level also are indicated in the table. The Marshall flour (24.3 Farrand units of starch damage) baked using the sponge and dough method showed the lowest water activity level when baked at 52.7% absorption. In general, the water activity remained in the 0.995–0.970 range for all samples used in the study, but there was a reduction in bread crumb moisture during the same four-day storage period.

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