Characterization and Utilization of Durum Wheat for Breadmaking. III. Staling Properties of Bread Baked from Bread Wheat Flours and Durum Wheat Flours[1]

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ABSTRACT

A staling study was conducted to investigate the staling properties of bread made with durum wheat flour and blends of bread and durum wheat flours. The effect of durum wheat flour on bread staling was estimated by measuring crumb moisture and firmness, as well as the total water-solubles, acetic acid solubles, and soluble starch content in the bread crumb. In addition, the scores of a sensory evaluation of the breads were analyzed. Incorporation of 25% durum wheat flour with a bread wheat flour resulted in a less firm crumb structure without any deficiency in such bread characteristics as color, flavor, mouthfeel, and freshness. The characterization of starch isolated from bread and durum wheat flours was also investigated.

In addition to its use in producing pasta, durum wheat also is used in the production of other products, such as bulgur, *couscous*, *frekeh*, puffed cereals, hot cereals, desserts, pastry filler, and, in some areas of the world, various types of bread (Dick and Matsuo 1988). In the Mediterranean area, and particularly in southern Italy, durum wheat has been, and continues to be, used in the formulation of several types of bread (Quaglia 1988). In the Middle East and North Africa, local breadmaking accounts for about half of the durum wheat consumption (Bozzini 1988).

Although durum wheat flour has been reported to reduce the bread staling rate (Quaglia 1988, Miazzi 1989, Quaglia et al 1989), relatively little work has been done regarding the effect of durum wheat flour on bread staling. Therefore, we investigated the staling properties of bread made with durum wheat flour and blends of durum and bread wheat flour.

The objective of this study was to investigate the staling properties of bread baked from durum flour, durum first clear flour, semolina, and bread wheat flour. Characterization of starch isolated from durum and bread flours was also undertaken, because the starch component in flour is generally recognized as the major contributor to the bread staling process.

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MATERIALS AND METHODS

Flour Samples

Flour samples were as described previously by Boyacioğlu and D'Appolonia (1994a).

Starch Samples

Starch was isolated from untreated bread flour, durum flour, durum first clear flour, and semolina by the dough kneading procedure of Walden and McConnell (1955). Moisture content of the isolated starch was determined according to the modified vacuum-oven method (AACC 1983). Apparent and total amylose contents of starch samples were determined using the method of Morrison and Laignelet (1983). The percent of amylopectin was calculated as 100 − % amylose (Hansen et al 1991). Intrinsic viscosity of the starch samples was determined using a Cannon-Ubbelohde semi-micro viscometer (International Research Glassware, Kenilworth, NJ) at 25°C in 1*N* NaOH, as described by Leach (1963).

Water-Binding Capacity and Water-Solubility Index

The water-binding capacity and water-solubility index were measured by the methods described by Medcalf and Gilles (1965) and Anderson et al (1969), respectively, with some modifications. Each starch sample (0.5 g of dry matter) was suspended in 10 ml of water in a tared, 15-ml centrifuge tube. The tube was capped with a rubber stopper, agitated on a multitube Vortexer (Scientific Manufacturing Industries, Emeryville, CA) at room temperature for 30 min, and centrifuged at 3,000 × *g* for 10 min. The supernatant was poured carefully into a tared evaporating dish. The remaining gel was weighed, and the amount of water held by the starch was determined. The water-binding capacity was calculated as grams of bound water × 100/0.5. The water-solubility index, expressed as percentage of dry solids in the 0.5-g sample, was calculated from the weight of dry solids recovered by evaporating the supernatant overnight at 110°C.

Starch Pasting Properties

Pasting properties of the starch samples were recorded by a Brabender Viscoamylograph (C. W. Brabender Instruments, South Hackensack, NJ), using the technique of D'Appolonia and MacArthur (1975). Pasting temperature, peak height, peak time, 15-min height, and set-back height were measured from the amylograph curve (Medcalf and Gilles 1966).

Differential Scanning Calorimetry

Differential scanning calorimetry (DSC) measurements were obtained with a Perkin-Elmer DSC-7 instrument equipped with a model 3700 thermal analysis data station and a graphics plotter 2 (Perkin-Elmer Corporation, Norwalk, CT).

Starch samples (~5 mg) were weighed accurately into aluminum pans. About 7.5 μl of distilled water was added, and the pans were sealed. The DSC analysis was performed from 10 to 130°C at the 10°C/min scanning rate to measure onset temperature, peak transition temperature, and transition enthalpy.

Baking Procedure

The straight-dough formula for 500-g scaled dough pieces (based on flour weight) was: 1,250 g of flour (14.0% mb), 3% yeast, 2% salt, 5% sugar, 3% shortening, and variable water.

Mixing was performed using a Hobart D 300-T mixer (Hobart Corporation, Troy, OH). The ingredients were added together and the dough was mixed to optimum using the following procedure. The dough was mixed 1 min at low speed, 1 min at medium speed, and to optimum development at high speed. After the mixing, the dough was removed from the mixing bowl, placed in a plastic container, and set in a 30°C fermentation cabinet.

After a 2-hr fermentation period with a single punch, the dough was scaled into 500-g pieces, rounded, allowed to rest at 30°C for 10 min, and then molded using a Moline molder (Moline Company, Duluth, MN). The panned loaves were proofed in 1-lb bread pans for 55 min at 43°C and 90% rh. The loaves were then baked in a Despatch oven for 25 min at 204°C. As listed in Table I, eleven kinds of bread were prepared: sample 1, bread made from the untreated bread flour and used as the control; samples 2–7, bread made from 100% durum wheat flours and from blends of durum wheat and bread wheat flours; sample 8, bread from the untreated bread flour containing ascorbic acid and sodium stearoyl-2-lactylate (SSL) as additives; samples 9–11, bread made from blends of durum wheat and bread wheat flours containg ascorbic acid and SSL. The loaves were removed from the pans and allowed to cool.

Sample Preparation

Two hours after removal from the oven, the weight and volume of the loaves were measured. The bread was then sliced (22 slices from each loaf), placed in polyethylene bags, and stored at room temperature. At 2 hr, and one, two, and three days after removal from the oven, bread samples were subjected to moisture determination and firmness measurement. After the firmness measurement, the crust was removed from the sliced bread, and the crumb was frozen immediately, it was then freeze-dried using a Virtis Consol 25LL freeze drier (Virtis Company, Gardiner, NY). The freeze-dried crumb was ground on a Thomas-Wiley laboratory mill (Arthur H. Thomas Company, Philadelphia, PA) to pass through a 1.0-mm screen. After the moisture determination, the freeze-dried bread crumb samples were used for isolation of total water-solubles, acetic acid solubles, and soluble starch.

TABLE I
Breads Investigated for Staling Study

Sample	Preparation
1	100% untreated bread flour (UBF)
2	100% durum flour (DF)
3	100% Durum first clear flour (DFCF)
4	100% Semolina (S)
5	25% DF + 75% UBF
6	25% DFCF + 75% UBF
7	25% S + 75% UBF
8	100% UBF + 75 ppm of ascorbic acid (AA) + 0.5% sodium stearoyl lactylate (SSL)
9	25% DF + 75% UBF + 75 ppm of AA + 0.5% SSL
10	25% DFCF + 75% UBF + 75 ppm of AA + 0.5% SSL
11	25% S + 75% UBF + 75 ppm of AA + 0.5% SSL

Crumb Moisture and Firmness Measurements

Bread moisture was determined according to the modified two-step air-oven method (AACC 1983). Bread crumb (10 g) was removed by cutting plugs from one center slice and from a slice at each end of the loaf. Care was taken to be consistent in all loaves. Firmness of the bread samples was measured on a Universal Testing Machine (model 1000, Instron Corporation, Canton, MA), according to AACC approved method 74-09. The force needed to achieve a 25% compression was calculated by using a mean compression force value and was expressed in newtons.

Isolation of Total Water-Solubles, Acid Solubles, and Soluble Starch

The total water-soluble content of the bread crumb was determined according to Kim and D'Appolonia (1977) and Morad and D'Appolonia (1980). The water-soluble material was extracted by adding 30 ml of distilled water to 5 g of freeze-dried bread crumb and agitating the mixture on a Burrell wrist-action shaker (Burrell Corporation, Pittsburg, PA) for 20 min. The slurry was centrifuged (2,000 × g for 5 min), and the supernatant was filtered through a prepleated filter paper. The procedure was repeated twice on the residue. The combined supernatants were then frozen and freeze-dried.

The acid soluble content of the bread crumb was determined according to Kim and D'Appolonia (1977). The acetic acid solubles were extracted from the freeze-dried bread crumb by shaking the crumb (2 g) with 30 ml of 0.05N acetic acid on a Burrell wrist-action shaker for 30 min. The slurry was centrifuged (2,000 × g for 20 min), filtered, frozen, and freeze-dried.

The procedure of Schoch and French (1947), as modified by Morad and D'Appolonia (1980), was used to isolate the soluble starch content in the total water-solubles extracted from the bread crumb before freeze-drying. Three volumes of methanol were added to the total water-solubles, and the mixture was heated in a steam bath for 1 hr and left overnight at 4°C. The flocculated soluble starch was collected by centrifugation (16,300 × g for 20 min), dispersed in 25 ml of distilled water, frozen, and freeze-dried.

Sensory Evaluation

The nine-point hedonic rating scale (1 = low, 9 = high) was used for preference testing on samples 8–11 (Table I). Four 1-lb loaves of bread were produced from every batch, using the straight-dough method as previously described; they were removed from the oven after 2 hr, sliced, stored in polyethylene bags, and kept at room temperature. Two-day stale bread slices were cut into two parts vertically and placed into zipper sandwich bags. Randomly chosen numbers were used for the bread slices from the different samples. A panel of 75 untrained participants evaluated the samples for color, flavor, mouthfeel, freshness, and overall preference.

Data Analysis

The data for starch characterization, staling, and sensory evaluation were analyzed using the general linear model (SAS 1985). Separate analyses of variance were run for each day and for an overall analysis to test for differences in rates of change for the staling variable over four days in storage. The overall analysis yielded estimated regression coefficients. When analysis of variance indicated significant differences among means for starch sources and flour preparation, Duncan's multiple range test was used to compare all pairs of means.

RESULTS AND DISCUSSION

The importance of starch in bread staling is well documented, so the starch isolated from the untreated bread flour, durum flour, durum first clear flour, and semolina, was characterized.

Apparent and Total Amylose and Amylopectin Content

Table II shows the apparent amylose content values for the starches with lipids present and the total amylose content for the lipid-free starches isolated from bread and durum wheat flours. According to the Duncan's multiple range test, semolina starch had a significantly lower amount of apparent amylose than did the other starches. Starch isolated from the untreated bread flour showed a significantly higher value for total amylose and, consequently, a lower value for amylopectin. The difference between apparent and total amylose is a measure of amylose complexing by the lipids (Morrison and Laignelet 1983, Soulaka and Morrison 1985a). Therefore, bread wheat flour starch appeared to have a higher lipid-binding ability. Soulaka and Morrison (1985b) showed that a normal variation in the amylose content of wheat starches has no effect on baking quality.

Intrinsic Viscosity, Water-Binding Capacity, and Water-Solubility Index

Untreated bread flour starch gave the lowest intrinsic viscosity value among the various starches (Table III). Intrinsic viscosity is essentially a measure of the internal friction or resistance to displacement of high-polymeric molecules in solution. In fundamental starch studies, intrinsic viscosity is the most useful and widely accepted index of molecular dimensions (Leach 1963). Medcalf and Gilles (1965) examined numerous wheat samples, including durum and hard red spring wheat, but reported no significant difference in intrinsic viscosity in the starch of these wheat classes.

Water-binding capacity and water-solubility index values for starch isolated from bread and durum wheat flours are presented in Table III. Duncan's multiple range test showed significant differences among the samples. Durum wheat starch, except for semolina starch, had slightly higher water-binding capacity than did untreated bread flour starch. These results agree with those of Medcalf and Gilles (1965), who reported generally higher water-binding capacity values for durum wheat starch than for bread wheat starch.

Based on the assumption that water-binding capacity of starch is affected by milling (Kulp 1973), semolina probably showed lower water-binding capacity values because in the durum milling process the resultant semolina is larger in particle size (less starch damage) than the flour obtained in a bread wheat mill. Mok and Dick (1991) found a significant difference in the water-solubility index between durum and bread wheat starch.

Pasting Properties

Table IV shows data on the pasting properties for the starch isolated from the different flours. According to Duncan's multiple range test, there was a significant difference between the bread and durum wheat starches in initial pasting temperature. The pasting temperature of the starches isolated from durum wheat was slightly higher than the pasting temperature of the untreated bread flour starch. Medcalf and Gilles (1965) reported that durum starch begins to swell at a slightly lower temperature than does starch from other wheat classes. Berry et al (1971) also showed a slightly lower initial pasting temperature for durum starch compared to that of hard red spring wheat starch.

Peak height shows the maximum viscosity obtained and, when compared with the 15-min height, gives an indication of the relative stability of the starch paste. The maximum viscosities of durum and hard red spring wheat starches were relatively stable during stirring at 95°C, which agrees with the findings of Medcalf and Gilles (1965). Set-back height values were significantly different among the starches. Peak time (minutes after the temperature first reached 95°C) also showed a significant difference among the starches, except for the semolina starch.

DSC

When wheat and other nonwaxy cereal starches are heated in limited quantities of water (as in baked goods), they exhibit complex endothermic transition patterns. However, when heated with sufficient water, the endothermic patterns simplify to a peak near 60°C, which is due to the melting point of amylopectin crystallites (the gelatinization temperature), and to a smaller peak near 100°C, which is due to dissociation of amylose-lipid complexes (Soulaka and Morrison 1985a). The onset and peak gelatinization temperatures of starch isolated from bread and durum wheat flours are presented in Table V; DSC thermograms are shown in Figure 1. Duncan's multiple range test showed significant differences in both onset and peak temperatures between the bread

TABLE II
Apparent and Total Amylose and Amylopectin Content (%) for Starch Isolated from Bread and Durum Wheat Flours[a,b]

	Apparent Amylose	Total Amylose	Amylopectin
Untreated bread flour	20.5 a	28.1 a	71.9 b
Durum flour	20.9 a	25.1 b	74.9 a
Durum first clear flour	21.1 a	24.4 b	75.6 a
Semolina	18.9 b	24.7 b	75.3 a

[a] Means followed by the same letter in columns are not significantly different at $P = 0.05$ according to Duncan's multiple range test.
[b] Values represent the mean of four replicates.

TABLE III
Intrinsic Viscosity, Water-Binding Capacity, and Water-Solubility Index of Starch Isolated from Bread and Durum Wheat Flours[a]

	Intrinsic Viscosity[b] (Centistokes)	Water-Binding Capacity[c] (%)	Water-Solubility Index[c] (%)
Untreated bread flour	2.09 b	89 c	1.20 b
Durum flour	2.15 ab	91 b	1.60 a
Durum first clear flour	2.20 a	99 a	0.77 c
Semolina	2.21 a	85 d	0.57 d

[a] Means followed by the same letter in columns are not significantly different at $P = 0.05$ according to Duncan's multiple range test.
[b] Values represent the mean of two replicates.
[c] Values represent the mean of three replicates.

TABLE IV
Pasting Properties of Starch Isolated from Bread and Durum Wheat Flours[a]

	Pasting Temperature (°C)	Peak Height (BU)	Peak Time (min)[b]	15-Min Height (BU)	Set-Back Height (BU)
Untreated bread flour	82.0 c	360 c	95 + 15 a	360 c	620 c
Durum flour	83.0 b	380 b	95 + 6 c	370 b	680 a
Durum first clear flour	83.5 a	360 c	95 + 9 b	350 d	555 d
Semolina	83.0 b	405 a	95 + 15 a	405 a	640 b

[a] Means followed by the same letter in columns are not significantly different at $P = 0.05$ according to Duncan's multiple range test. Values represent the mean of two replicates.
[b] Minutes after the temperature first reached 95°C.

and durum wheat starches. As reported previously, starch isolated from the durum wheat had lower onset and peak temperatures than did starch isolated from the untreated bread flour. Medcalf and Gilles (1965) speculated that lower initial pasting temperature of durum starch may be related to a less compact granule structure in durum starch. However, Soulaka and Morrison (1985a) reported DSC results that showed similar gelatinization properties for bread and durum wheat starches.

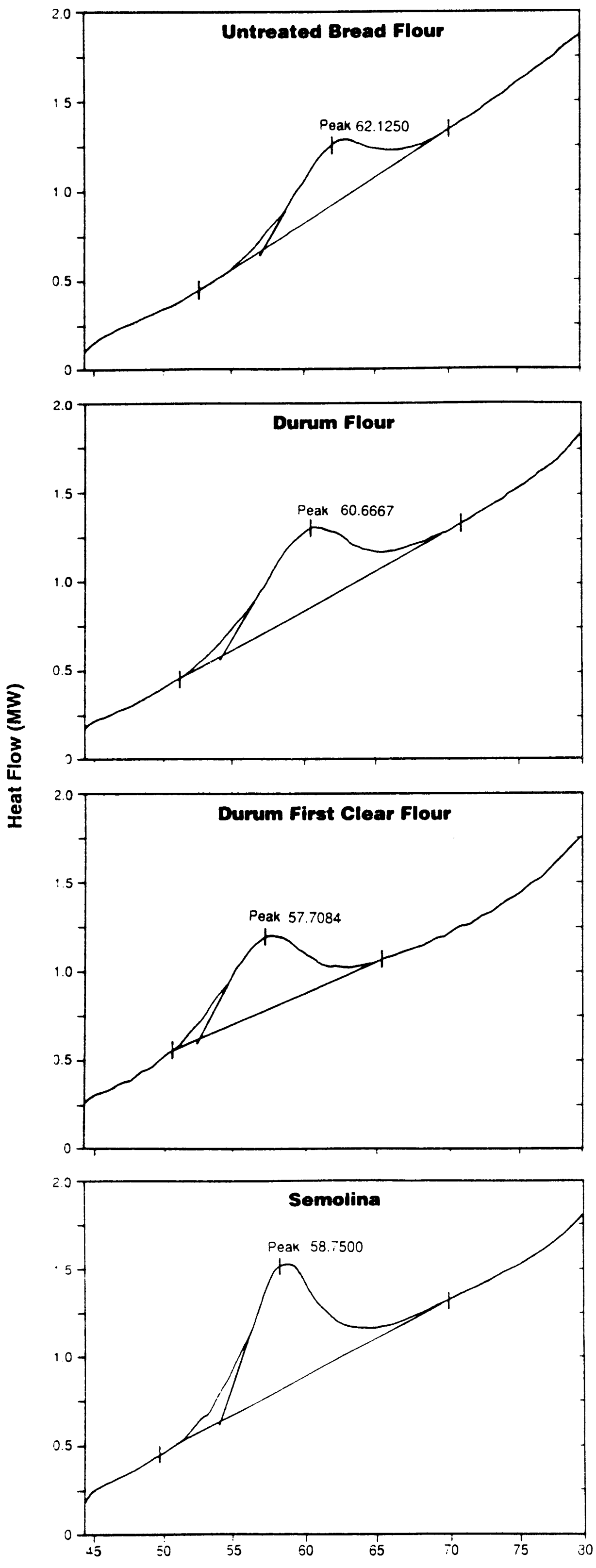

Fig. 1. Differential scanning calorimetry thermograms of starch isolated from bread and durum wheat flours.

The highest and lowest gelatinization temperatures were obtained from starch from untreated bread flour and durum first clear flour, respectively. Enthalpy, the amount of energy required for the gelatinization, was significantly different between bread and durum wheat flour starches, with the exception of semolina. According to Lund (1984), enthalpy of gelatinization is a linear function of the degree of gelatinization, thus it can be used directly as a measure of the amount of ungelatinized starch. Soulaka and Morrison (1985b) found no correlation between gelatinization enthalpy and loaf specific volume.

Staling Properties

The loaf volumes of breads used for the staling study are shown in Table VI. Samples 2 (durum flour), 3 (durum first clear flour), and 4 (semolina) had loaf volumes that were significantly lower than those of sample 1 (untreated bread flour). However, samples 5–7 (25:75 blends containing durum flours or semolina) had loaf volumes similar to that of sample 1 (control). Furthermore, samples 9–11 (blends with ascorbic acid and SSL additives) had loaf volumes that were higher than those of any other sample, including sample 8 (untreated bread flour with ascorbic acid and SSL). These results confirmed the data reported by Boyacioğlu and D'Appolonia (1994b) using 100-g pup loaves.

The untreated bread flour showed the highest loaf volume, and its starch had the highest gelatinization temperature and enthalpy values (Tables V and VI). These results agree with those of Soulaka and Morrison (1985b), who stated that anything that delays starch gelatinization (e.g., higher gelatinization temperature and enthalpy) could prolong the period of loaf expansion and, hence, increase loaf volume.

Axford et al (1968) studied the effect of loaf volume on the rate of staling and found that lower specific volume increased the staling rate and that higher specific volume lowered the staling rate. Maleki et al (1980) found that a larger loaf size produced softer bread. Ponte and Faubion (1985) also reported that volume has an influence on crumb rheology and firming.

TABLE V
Differential Scanning Calorimetry Data of Starch Isolated from Bread and Durum Wheat Flours[a]

	Temperature (°C)		
	Onset	Peak	Enthalpy[b]
Untreated bread flour	57.6 a	62.1 a	5.67 a
Durum flour	54.5 b	60.7 b	4.69 ab
Durum first clear flour	52.8 c	57.7 d	3.71 b
Semolina	54.2 b	58.8 c	5.44 a

[a] Means followed by the same letter in columns are not significantly different at $P = 0.05$ according to Duncan's multiple range test. Values represent the mean of two replicates.
[b] Joules per gram.

TABLE VI
Loaf Volume (cm^3) Data for Breads Investigated for Staling Study[a]

Sample	Loaf Volume, cm^3
1	2,519 c
2	2,044 d
3	1,678 f
4	1,913 e
5	2,534 c
6	2,506 c
7	2,528 c
8	2,788 b
9	2,888 a
10	2,906 a
11	2,881 a

[a] Means followed by the same letter in columns are not significantly different at $P = 0.05$ according to Duncan's multiple range test. Values represent the mean of eight replicates.

Bread Moisture

The moisture content of breads during storage is presented in Table VII. Each bread sample showed a definite decrease in crumb moisture during storage. This might be expected because most plastic bags are permeable to moisture vapor (Rogers et al 1988). Samples within the same day displayed a significant change overall. However, bread made from semolina (4), and from semolina blends with and without additives (7 and 11), had a lower moisture content than did the other breads. Bread containing 25% semolina (7) showed the least change in moisture content per day over the four-day storage period. Bread containing 25% semolina with ascorbic acid and SSL (11) showed the greatest change in moisture content, according to the regression coefficients (Table VII). The data indicate that durum wheat blends had less change in moisture content per day than did untreated bread flour (1).

Bechtel and Meisner (1954) concluded that bread with high crumb moisture content was significantly fresher than bread with low moisture content. According to Kulp (1979), higher moisture content improves both crust and crumb freshness. Maleki et al (1980) found the moisture content of bread affects the absolute softness but not the staling rate. Rogers et al (1988) showed that moisture content is a major factor regulating the firming rate in bread, and that moisture content is inversely proportional to the rate of firming.

Several authors have commented on the contribution of moisture retention to the shelf life of durum wheat bread. Salman and Clark (1913) stated that bread from durum flour holds moisture better than bread from other flours. Luraschi (1955) reported that durum wheat flour has a higher water-binding capacity than does bread wheat flour, which accounts for the slower staling and, consequently, longer shelf life of bread made from durum wheat flour. Pattakou explained that the ability of durum wheat bread to stay fresh longer may be due to less water loss from the crumb because of the thicker crust of durum wheat bread.

Bread Firmness

Firmness is one of the most important textural properties of bread for consumer acceptance. Bice and Geddes (1949) concluded that firmness and crumbliness are related closely to the organoleptic assessment of staleness. Table VIII shows the firmness values of breads during storage and the change in firmness per day over the storage period. As storage time increased, firmness values for each bread increased, due to increases in crumb rigidity. The initial firmness of bread made from 100% durum wheat flour or semolina (2–4) was higher than that of bread made from the untreated bread flour (1). The low firmness values of breads made with untreated bread flour could be attributed to the higher loaf volumes, as reported previously. Likewise, the high firmness values of breads made from 100% durum first clear flour could be a result of the lower loaf volumes. Also, the starch obtained from

TABLE VII
Moisture Content (%) of Breads During Storage[a]

Sample[b]	Days of Storage 1	2	3	4	Regression Coefficient[c]
1	44.6 ab	44.3 bc	43.8 abc	43.2 ab	−0.49
2	45.9 a	45.6 a	44.9 a	44.1 a	−0.60
3	45.2 ab	44.7 ab	44.3 ab	43.0 ab	−0.69
4	41.8 c	41.8 d	41.3 d	40.6 b	−0.41
5	44.3 ab	44.3 bc	43.6 abc	43.2 ab	−0.42
6	44.6 ab	44.3 bc	43.9 ab	43.3 ab	−0.45
7	43.2 bc	43.6 bc	43.3 abc	42.4 ab	−0.26
8	44.0 abc	44.0 bc	43.7 abc	41.9 ab	−0.66
9	43.6 abc	43.6 bc	43.3 abc	42.4 ab	−0.39
10	43.7 abc	43.4 c	43.2 bc	41.7 ab	−0.60
11	42.8 bc	42.1 d	42.1 cd	40.4 b	−0.72

[a] Means followed by the same letter in columns are not significantly different at $P = 0.05$ according to Duncan's multiple range test. Values represent the mean of two replicates.
[b] See Table I.
[c] Represents the change in moisture content per day over the storage period.

TABLE VIII
Firmness Values (N)[a] of Breads During Storage[b]

Sample[c]	Days of Storage 1	2	3	4	Regression Coefficient[d]
1	1.03 de	2.71 d	3.57 c	4.06 cd	1.00
2	1.57 c	3.48 c	4.20 b	4.59 c	0.98
3	3.85 a	6.14 a	6.28 a	7.90 a	1.23
4	1.89 b	4.97 b	5.97 a	6.94 b	1.61
5	0.91 e	2.41 de	3.11 c	3.63 cde	0.89
6	1.15 d	2.40 de	3.30 c	3.77 cde	0.88
7	0.98 e	2.19 de	3.28 c	3.88 cd	0.98
8	1.02 de	2.07 e	2.56 d	3.31 de	0.74
9	0.88 e	1.91 e	2.49 d	2.78 e	0.63
10	0.97 e	1.84 e	2.38 d	2.77 e	0.59
11	1.02 de	2.07 e	2.54 d	3.00 de	0.64

[a] Measured in newtons.
[b] Means followed by the same letter in columns are not significantly different at $P = 0.05$ according to Duncan's multiple range test. Values represent the mean of two replicates.
[c] See Table I.
[d] Represents the change in firmness per day over the storage period.

untreated bread flour had a higher amylose content than did the starch of durum wheat flours (Table II). Inagaki and Seib (1992) stated that amylose may play a passive role in the firming of bread crumb. Untreated bread flour may have showed lower firmness values because of its higher amylose content. The moisture content (which affects the rate of firming) of these breads also varied greatly during four days of storage.

Bread containing 25% durum flour (5) or semolina (7) gave initial firmness values that were significantly lower than that of the 100% durum wheat bread. The additives did not improve initial firmness, but they did retard the firming during the second, third, or fourth day of storage; this was also reported by other researchers.

At the fourth day of storage, bread from the durum flour (2) had a firmness value similar to that of the bread made from the untreated bread flour (1); durum first clear bread (3) and semolina bread (4) showed firmness values that were significantly higher than those of the other breads. As observed for the first day, the firmness values of bread blends made from durum flour, durum first clear flour, and semolina (samples 5–7) were lower than those of the 100% durum wheat breads (2–4), but the firmness values did not differ from that of bread made from untreated bread flour (1). The effect of additives on the firmness values for blended breads (9–11) was more significant than it was for the 100% durum wheat breads (2–4). After four days of storage, the breads made with 25% blended durum flour and durum first clear flour with additives (9–10) had firmness values similar to that of the bread made from the untreated bread flour without any additive (1) at the second day of storage. The change in firmness per day during storage was higher for the semolina bread (4) than it was for the remaining breads. However, the bread containing 25% durum flour (5) or durum first clear flour (6) showed less increase in firmness than did the control bread (1). Incorporation of ascorbic acid and SSL decreased the change in firmness per day for breads made with the control flour and various blends (8–11). The breads containing 25% durum flour, or durum first clear flour, or semolina with ascorbic acid and SSL (9–11) showed less increase in rate of firmness than did the bread from the untreated bread flour with ascorbic acid and SSL (8).

Total Water-Soluble Content

Table IX shows the total water-soluble content recovered from bread crumb during storage. The yield of solubles decreased as the bread aged. The amount of total water-solubles extracted from the bread made with the durum wheat flours (2–4) was considerably higher than that extracted from the control bread (1). Blending and the use of additives decreased the yield of solubles. Morad and D'Appolonia (1980) reported that the amount of extractable water-soluble material in bread crumb decreased at a faster rate during the first 12 hr of storage than it did thereafter, with or without surfactants. They added that, during the early storage period, the amount of water-solubles extracted from the bread crumb with surfactants was lower than

TABLE IX
Total Water-Soluble Content (%, dry matter basis) Extracted from Bread Crumb During Storage[a]

Sample[b]	Days of Storage 1	2	3	4	Regression Coefficient[c]
1	9.42 fg	8.91 fg	8.82 ef	8.55 c	−0.27
2	13.77 b	13.65 b	13.59 b	13.44 a	−0.11
3	14.69 a	14.56 a	14.51 a	14.27 a	−0.13
4	10.95 c	10.59 c	10.42 c	10.26 b	−0.22
5	10.28 de	10.11 cd	10.03 cd	9.87 bc	−0.13
6	10.50 cd	10.24 cd	9.98 cd	9.61 bc	−0.29
7	9.79 ef	9.39 ef	8.83 ef	8.61 c	−0.41
8	8.97 g	8.68 g	8.11 f	7.13 d	−0.61
9	10.12 de	9.72 de	9.39 de	9.06 bc	−0.35
10	10.29 de	10.04 d	9.70 cde	9.12 bc	−0.39
11	9.42 fg	9.12 fg	8.89 ef	8.58 c	−0.28

[a] Means followed by the same letter in columns are not significantly different at $P = 0.05$ according to Duncan's multiple range test. Values represent the mean of two replicates.
[b] See Table I.
[c] Represents the change in total water-solubles per day over the storage period.

TABLE X
Acetic Acid Soluble Content (%, dmb) Extracted from Bread Crumbs During Storage[a]

Sample[b]	Days of Storage 1	2	3	4	Regression Coefficient[c]
1	8.19 e	7.93 g	7.86 g	7.71 f	−0.15
2	13.02 a	12.58 a	12.49 a	12.31 a	−0.22
3	13.14 a	13.02 a	12.69 a	12.65 a	−0.18
4	10.68 b	10.32 b	9.98 b	9.80 b	−0.30
5	9.46 c	9.56 cd	9.42 c	9.03 c	−0.20
6	9.78 c	9.70 c	9.40 c	9.32 c	−0.17
7	8.91 d	8.84 ef	8.59 de	8.48 d	−0.15
8	8.23 e	8.17 g	8.11 fg	7.80 ef	−0.08
9	9.23 cd	9.08 de	9.00 cd	8.95 c	−0.09
10	9.60 c	9.44 cd	9.42 c	9.17 c	−0.13
11	8.65 de	8.46 fg	8.37 ef	8.24 de	−0.13

[a] Means followed by the same letter in columns are not significantly different at $P = 0.05$ according to Duncan's multiple range test. Values represent the mean of two replicates.
[b] See Table I.
[c] Represents the change in acetic acid solubles per day over the storage period.

TABLE XI
Soluble Starch Content (% dmb) Extracted from Bread Crumbs During Storage[a]

Sample[b]	Days of Storage 1	2	3	4	Regression Coefficient[c]
1	1.07 b	0.85 ab	0.47 b	0.43 ab	−0.23
2	1.13 b	0.80 ab	0.52b	0.31 b	−0.27
3	1.72 a	1.40 a	1.19 a	0.71 a	−0.32
4	0.74 b	0.58 b	0.48 b	0.29 b	−0.15
5	0.96 b	0.87 ab	0.43 b	0.39 ab	−0.22
6	1.23 ab	1.09 ab	0.39 b	0.32 b	−0.35
7	1.01 b	0.85 ab	0.52 b	0.35 b	−0.23
8	1.18 b	0.91 ab	0.76 ab	0.49 ab	−0.22
9	1.03 b	0.89 ab	0.69 ab	0.51 ab	−0.18
10	1.06 b	0.57 b	0.55 b	0.35 b	−0.22
11	1.02 b	0.75 b	0.59 b	0.33 b	−0.22

[a] Means followed by the same letter in columns are not significantly different at $P = 0.05$ according to Duncan's multiple range test. Values represent the mean of two replicates.
[b] See Table I.
[c] Represents the change in soluble starch per day over the storage period.

that obtained from the control. At four days of storage, bread made from 100% durum flour (2) and durum first clear flour (3) showed the highest amount of water-solubles. The bread made with 100% of durum flour (2) showed the least change in total water-soluble content per day. The bread made from 100% untreated bread flour with ascorbic acid and SSL (8) showed the greatest amount of change per day in total water-soluble content.

Acetic Acid Soluble Content

The amounts of acetic acid solubles recovered from bread crumb during storage are presented in Table X. As the bread aged, the yield of the acetic acid solubles from bread crumb decreased; these results were similar to those of Kim and D'Appolonia (1977). The acetic acid solubles in bread made with the durum wheat flours (2–4) were significantly higher than that in the control bread (1). Overall, data for the acetic acid soluble content of breads were similar to those of the total water-soluble content. Blending decreased acetic acid soluble content (5–7). With the exception of the untreated bread flour bread (8), ascorbic acid and SSL additives decreased acetic acid soluble content. At four days of storage, all bread made from the durum flours (2–4), the durum flour blends (5–7), and the durum flour blends with additives (9–11), yielded higher amounts of acetic acid solubles than did the control breads (1 and 8). The addition of ascorbic acid and SSL decreased the rate of change per day in acetic acid soluble content over the four-day storage period. The bread made from 100% untreated bread flour with ascorbic acid and SSL (8) had the smallest rate of change per day in acetic acid soluble content during storage.

Soluble Starch Content

The amount of soluble starch extractable from bread crumb decreases as storage time increases (Bice and Geddes 1949, Kim and D'Appolonia 1977). Soluble starch content is therefore used to measure rate and degree of staling. The effect of staling on the quantity of soluble starch extracted from crumb produced from bread and durum wheat flours and their blends is shown in Table XI. The soluble starch content decreased progressively as the bread aged. At the first day of staling, only bread made from durum first clear flour (3) and its 25% blend (6) had an amount of soluble starch that was considerably higher than that of the remaining breads. The durum first clear flour bread (3) had the highest amount of soluble starch at the fourth day of storage. The rate of change per day in soluble starch content for bread made with 100% semolina (4) was the lowest of all breads. All breads made with ascorbic acid and SSL (8–11) had similar values for the rate of change per day in soluble starch content, as shown by the regression coefficients.

TABLE XII
Sensory Evaluation Data[a] of Bread

Sample[b]	Color	Flavor	Mouthfeel	Freshness	Overall
8	6.8	6.4	6.4	6.7	6.5
9	6.8	6.2	6.2	6.7	6.2
10	6.7	6.1	6.3	6.6	6.3
11	6.7	6.1	6.2	6.5	6.3

[a] Values represent the mean of 75 panelists. Scores based on scale of 1–9 (1 = low, 9 = high).
[b] See Table I.

Sensory Evaluation

Determining staleness by sensory evaluation is basically a consumer judgment concerning: firmness of the crumb, the feel of the surface of a cut slice, odor, flavor, and mouthfeel. A taste panel uses these sensory perceptions to judge whether bread is fresh or stale (Bechtel and Meisner 1951, Pomeranz 1987). In this study, 75 panelists made a sensory evaluation of bread samples using a nine-point hedonic rating scale (1 = low, 9 = high). The panelists were asked to evaluate the samples for color, flavor, mouthfeel, freshness, and overall preference. The results of the sensory evaluation are presented in Table XII. Analysis of variance was not significantly different for any characteristic between breads made with untreated bread flour (1) and the durum flour blends with additives (9–11).

Bread made from 100% durum flour, durum first clear flour, or semolina (2–4) was firmer than bread made from untreated bread flour (1), but yielded higher amounts of water-solubles, acetic acid solubles, and soluble starch. In contrast, bread with durum flour blends, with or without additives (5–7 or 9–11, respectively) were less firm than bread from untreated bread flour, with or without additives (1 or 8, respectively). Most importantly, taste panel evaluations showed no difference in breads containing 25% durum wheat flours from those made from 100% bread wheat flour. Incorporation of durum wheat flours with a bread wheat flour (25:75) resulted in a crumb structure that was less firm than that of breads made from 100% bread wheat flour, but there were no deficiencies in bread characteristics such as color, flavor, mouthfeel, and freshness.

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