Characterization and Utilization of Durum Wheat for Breadmaking. I. Comparison of Chemical, Rheological, and Baking Properties Between Bread Wheat Flours and Durum Wheat Flours[1,2]

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ABSTRACT

Durum wheat is traditionally used to produce pasta products. Certain countries, however, use durum wheat for breadmaking. More information relevant to the use of durum wheat in breadmaking could increase the utilization and value-added potential of durum wheat in domestic and export markets. One durum flour, three durum first clear flours, one durum second clear flour, one semolina, and three bread wheat flours were studied to determine differences in chemical, rheological, and baking properties of the bread and durum wheat flours. Based on these results, the durum flour rated best for breadmaking potential among the durum wheat flours. Incorporating bread additives and modifying baking procedures could result in bread with more acceptable characteristics.

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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. However, its use in breadmaking has been restricted because durum wheat gluten protein generally lacks the elastic strength of some of the strongest bread wheats (Dick 1987, Dick and Matsuo 1988, Boggini and Pogna 1989).

New cultivars of durum wheat with stronger gluten properties and superior pasta-making quality have been introduced in the United States, Canada, and Italy. Results of research with these new durum cultivars challenge the long-established belief that durum wheat is suitable for high-quality pasta production but not for breadmaking (Dexter et al 1981, Josephides 1982, Quick and Crawford 1983, Boggini 1985, Holm 1985, Boggini et al 1988, Boggini and Pogna 1989, Olmedo 1989).

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 (Varughese 1975, Srivastava 1983, Williams et al 1984, Bozzini 1988).

Additional information on the use of durum wheat in breadmaking could increase the utilization and value-added potential of durum wheat in domestic and export markets. From an economic perspective, a study of the utilization of durum clear flour in breadmaking could increase the commercial value of durum clear flour and offset the cost of semolina.

The objective of this study was to determine differences in the chemical, rheological, and baking properties of durum flour, durum clear flour, semolina, and bread wheat flour.

MATERIALS AND METHODS

Flour Samples

Nine flour samples were used to determine the differences in the chemical, rheological, and baking properties of durum flour, durum clear flour, and semolina with bread wheat flour. Samples of commercial flours obtained from the North Dakota Mill and Elevator, Grand Forks, ND, were: durum flour, durum first clear flour 1, durum first clear flour 2, semolina, and bakers commercial flour. Samples of commercial flours obtained from Turkey were: durum first clear flour 3, durum second clear flour, and bread flour. Durum first clear flour 3 was the composite sample obtained from the Piyale and Kartal Pasta Co., Izmir, Turkey. Durum second clear flour and bread flour were obtained from the Beslen Pasta Company, Gaziantep and Hilal Flour Mill, Izmir, Turkey. Untreated bread flour was derived from the cultivar Len, a hard red spring wheat, and milled on a Miag pilot mill in the Department of Cereal Science and Food Technology, North Dakota State University, Fargo, ND. The sample was unbleached and untreated.

Chemical Analysis

Moisture, protein, and ash content of the flours were determined according to AACC approved methods 44-15A, 46-11A, and 08-11, respectively (AACC 1983). Protein content of the flour was calculated as N × 5.7.

Wet gluten content was determined according to AACC approved method 38-11, except that a Glutomatic 2200 (Falling Number AB, Huddinge, Sweden) was used instead of a Theby gluten washer.

Microsedimentation height values were determined according to the procedure developed by Dick and Quick (1983).

Sugars in flour samples were extracted with the ternary solvent system of Ponte et al (1969), as modified by MacArthur and D'Appolonia (1979). Total sugars were determined by the phenol-sulfuric acid colorimetric method of Dubois et al (1956) on a Lambda 3B UV/VIS spectrophotometer (Perkin-Elmer, Norwalk, CT).

Pentosan content was determined according to the procedure of Dische and Borenfreund (1957), as modified by Cracknell and Moye (1970) and outlined by MacArthur and D'Appolonia (1977), using a spectrophotometer.

The amount of starch and starch damage in the flour samples was determined using AACC approved methods 76-11 and 76-30A, respectively. Falling number and the diastatic activities of all flours were determined according to AACC approved methods 56-81B and 22-10, respectively.

The pigment content of the flour samples was determined according to AACC approved method 14-50, with modifications described by Johnston et al (1980), on a spectrophotometer. The predominant pigments in durum wheat are xanthophylls or luteins, not carotenes (Sims and Lepage 1968), so pigment content was determined using the wavelength for free lutein (449.0 nm) on each sample.

Physical Dough Properties

Farinograph, mixograph, and alveograph tests were performed according to AACC approved methods 54-21, 54-40A, and 54-30, respectively.

Physical properties of the flour doughs were characterized with

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the Brabender extensigraph (C. W. Brabender Instruments, Inc., South Hackensack, NJ), using the AACC approved method 54-10 with the following modifications: 100 g (14.0% mb) of flour were mixed to optimum development in a standard National dough mixer (National Manufacturing Company, Lincoln, NE) with 20 ml of solution (1.0% sodium chloride, 0.003% potassium bromate) and water to equal farinograph absorption (%) minus 2.0%. After they were mixed, the doughs were scaled to 150 g, rounded in the extensigraph dough rounder, molded, and placed in the dough holders (cradles). After a 45-min rest at 30°C and 80% rh, the dough piece was stretched on an extensigraph to obtain a curve. The dough was then placed in a bowl in the humidity cabinet and rested for an additional 90 min, after which it was rounded, molded, placed on an extensigraph holder, and returned to the cabinet for an additional 45 min. The dough was then stretched on the extensigraph, and a second curve was superimposed over the first one. The second curve represented the 180-min rest period.

A Brabender maturograph was used to determine the proofing properties, and an oven-rise recorder was used to determine the change in volume of a dough during the entire baking process. Both tests were performed by W. Sietz, Brabender OHG, Duisburg, Germany, according to the standard method described by Seibel (1968).

Bread Properties

The formula (based on flour weight) for the straight-dough method used to bake 100-g loaves of bread was: 100 g of flour (14.0% mb), 3% yeast, 2% salt, 5% sugar, 3% shortening, 15 (Sandstedt-Kneen-Blish, SKB) units of fungal amylase, and variable absorption.

All ingredients were mixed to optimum dough development in a mixing bowl (National, 100–200 g). A 2-hr fermentation period at 30°C and 78% rh was used, with punching after 55 min and again after 40 min. The dough was sheeted through sheeting rolls and then molded on a National Roll-Er-Up molder after a total fermentation time of 2 hr. The dough was proofed for 55 min in a fermentation cabinet under controlled temperature (30°C) and relative humidity (78%) and then baked for 25 min at 221°C in a reel-type test baking oven (National).

Weight and volume were measured 1 hr after removal of bread loaves from the oven. Loaf volume was determined by rapeseed displacement using a loaf volumeter. The external appearance (break, shred, symmetry) and internal appearance (crust color, grain and texture of the crumb, and crumb color) were compared to that of the control loaf and scored the following day. Scores for all bread characteristics were from 1 (lowest) to 10 (highest).

RESULTS AND DISCUSSION

Protein Content and Wet and Dry Gluten Values

The protein content of the durum wheat flour is slightly higher than that of bread flour (Table I). The difference in protein content between durum and bread wheats, and the corresponding flours, has been reported by numerous researchers (Toepfer et al 1972, Huebner and Wall 1976, Wall 1979, Simmonds 1978, Dick 1981, Feillet 1988, Pomeranz et al 1988, Pyler 1988, Milatović and Mondelli 1991, Lindahl and Eliasson 1992).

The durum wheat flours also had a higher wet and dry gluten content than did the bread wheat flours. This could be expected; the significant correlation between wet and dry gluten values and protein content is well known. According to Quaglia (1988), durum wheat flour is generally characterized by a protein and gluten content that is relatively higher than that of Italian hard wheat flour.

Microsedimentation Height Values

Dexter et al (1981) and Holm (1985) showed that the microsedimentation height values, which indicate gluten strength, are higher for bread wheat flours. These results, pertaining to the quality and quantity of durum wheat and bread wheat proteins, are quite consistent with available information. The durum wheat proteins have different physical and chemical characteristics. Traditionally, durum wheat gluten has been softer, more sticky, more extensible, and less elastic than hard wheat glutens (Gilles 1967, Risdal 1971, Matz 1987). Huebner and Wall (1976) reported that durum flours are high in protein but have a disproportionately high content of gliadins (low molecular weight proteins) and a low proportion of insolubles.

Ash and Pigment Content

The ash content of the durum flour samples was higher than that of the bread wheat flours (Table II). Clear flours represent, primarily, the outer parts of the kernel, so there was a large difference between the ash contents of the clear flours and those of the other samples.

The free lutein amounts were considerably higher in the durum samples (Table II). The bakers commercial flour showed very little pigment because the sample had been bleached. According

TABLE I
Protein, Wet and Dry Gluten, and Microsedimentation Height Values[a]

Flour Sample	Protein[b] (%)	Wet Gluten[b] (%)	Dry Gluten[b] (%)	Micro-Sedimentation Height (mm)
Durum flour	15.0	42.9	14.5	32
Durum first clear flour 1	13.7	38.2	13.3	28
Durum first clear flour 2	16.4	41.3	14.5	32
Durum first clear flour 3	10.9	28.7	10.0	21
Durum second clear flour	9.6	25.8	8.4	22
Semolina	14.4	39.6	14.9	18
Bakers commercial flour	12.5	32.1	11.3	68
Bread flour	9.9	25.0	8.9	53
Untreated bread flour	14.5	36.1	12.8	80

[a] Values represent the mean of two replicates.
[b] Based on a 14.0% moisture level.

TABLE II
Ash and Pigment Values[a]

Flour Sample	Ash[b] (%)	Free Lutein[c] (ppm)
Durum flour	0.86	7.16
Durum first clear flour 1	1.38	5.47
Durum first clear flour 2	1.48	6.54
Durum first clear flour 3	1.41	4.22
Durum second clear flour	1.16	3.91
Semolina	0.75	5.68
Bakers commercial flour	0.43	0.88
Bread flour	0.52	2.16
Untreated bread flour	0.41	2.03

[a] Calculations are based on a 14.0% moisture level.
[b] Values represent the mean of three replicates.
[c] Values represent the mean of four replicates.

TABLE III
Total Sugar and Pentosan Values[a]

Flour Sample	Total Sugar[b] (%)	Pentosans[c] (%)
Durum flour	3.0	1.7
Durum first clear flour 1	3.4	2.1
Durum first clear flour 2	3.5	2.1
Durum first clear flour 3	3.7	2.6
Durum second clear flour	3.5	2.1
Semolina	2.8	1.8
Bakers commercial flour	1.8	1.8
Bread flour	2.1	2.2
Untreated bread flour	2.0	1.9

[a] Calculated on a dry matter basis.
[b] Values represent the mean of three replicates.
[c] Values represent the mean of two replicates.

to Quaglia (1988), yellow color, together with taste and shelf life, represent the fundamental index of quality for durum wheat bread.

Total Sugar and Pentosan Content

The total sugar content of durum wheat samples was higher than that of bread wheat flours (Table III) (Toepfer et al 1972, Holm 1985). Clear flours contain more of the outer layer of the wheat kernel, which has a higher sugar content than the endosperm does (MacArthur and D'Appolonia 1976). Bran also contains greater amounts of sugar than the endosperm does (Cerning and Guilbot 1974). The ash content of the durum wheat flours, containing more bran material, was higher than that of the bread wheat flour. The difference in total sugar content between durum and bread wheat flours might also be due to the higher levels of damaged starch in the durum wheat flours.

The pentosan contents of the durum samples and the bread wheat flours were similar, except for that of the durum clear flours. Pentosans are major endosperm cell-wall polysaccharides of wheat (Becker and Hanners 1991) and are found in greatest concentration in the low-grade flour fractions (Ciacco and D'Appolonia 1982, Pyler 1988). Therefore, the relationship between ash and total sugar content in high-extraction flours also applies for pentosan content.

TABLE IV
Total and Damaged Starch Values

Flour Sample	Total Starch[a] (%)	Damaged Starch[b] (%)
Durum flour	72.4	14.57
Durum first clear flour 1	65.7	13.77
Durum first clear flour 2	62.6	12.52
Durum first clear flour 3	66.7	10.64
Durum second clear flour	60.3	8.52
Semolina	71.9	5.19
Bakers commercial flour	72.8	9.43
Bread flour	73.5	7.16
Untreated bread flour	77.4	9.16

[a] Values represent the mean of two replicates calculated on a dry matter basis.
[b] Values represent the mean of four replicates calculated on a 14.0% moisture basis.

TABLE V
Falling Number and Amylograph Peak Viscosity Values[a]

Flour Sample	Falling Number (sec)	Peak Viscosity (BU)
Durum flour	501	1,250
Durum first clear flour 1	402	1,000
Durum first clear flour 2	570	1,550
Durum first clear flour 3	511	1,560
Durum second clear flour	502	1,420
Semolina	524	1,170
Bakers commercial flour	270	475
Bread flour	402	1,430
Untreated bread flour	391	1,960

[a] Values represent the mean of two replicates calculated on a 14.0% moisture basis.

Total and Damaged Starch Contents

The durum samples and the bread wheat flours had similar starch amounts (Table IV), with exception of the durum clear flours, which had a lower starch content. Although the outer layers of the wheat kernel are higher in ash, protein, and total sugars, this portion of the kernel is lower in starch (MacArthur and D'Appolonia 1977, Lineback and Rasper 1988, Pomeranz 1988 et al, Pyler 1988). Among the bread wheat flour samples, the bakers commercial flour and the bread flour both had less starch than did the untreated bread flour. This result was expected because these flour samples were patent flours, whereas the untreated bread flour was a straight-grade flour that would contain more of the external portion of the wheat kernel.

With the exception of semolina and durum second clear flour, durum wheat flours showed higher amounts of damaged starch than the bread wheat flours did. The bread wheat flours had more damaged starch than the semolina did. This was probably due to the use of smooth rollers during the bread flour milling process. Likewise, durum flour had more damaged starch than the other durum samples did, indicating greater milling severity.

Falling Number and Amylograph Results

Durum samples showed lower levels of α-amylase enzyme activity (higher falling number value) than bread flours (Table V). Bakers commercial flour had the lowest falling number, which is normal for a regular malted flour.

The higher falling number values of the durum wheat flours, compared to those of bread wheat flours, were also observed by Holm (1985). The higher falling number values for durum wheat flours may be due to the nature of the starch. A study conducted on durum wheat flours derived from Italian durum cultivars showed falling number values ranging between 264 and 526 sec (Boggini 1985). Quaglia (1988) indicated that these are very high values, and typical for wheat grown under dry, hot conditions and indicating low amylolytic activity.

Among the various samples evaluated, untreated bread flour recorded the maximum peak viscosity. As noted with its low falling number value, the bakers commercial flour showed the lowest peak viscosity. Berry et al (1971) reported slightly higher peak viscosity for hard red spring wheat flour compared to that of durum wheat flour.

Farinograph Data

Table VI gives summarized results for the farinograms shown in Figure 1. Except for the weak durum first clear flour 3, durum

TABLE VI
Farinograph Data[a]

Flour Sample	Absorption[b] (%)	Peak Time (min)	MTI[c] (BU)	Stability (min)	Classification Scale[d]
Durum flour	68.0	4.0	70	3.5	2
Durum first clear flour 1	68.4	2.5	60	4.5	2
Durum first clear flour 2	65.6	6.0	60	5.5	3
Durum first clear flour 3	60.0	2.5	160	3.0	1
Durum second clear flour	56.4	1.5	80	2.0	1
Semolina	55.6	5.5	80	4.5	2
Bakers commercial flour	60.0	8.0	20	12.5	5
Bread flour	58.4	5.0	50	6.5	4
Untreated bread flour	65.4	26.5	5	29.0	8

[a] Values represent the mean of two replicates.
[b] Calculation is based on a 14.0% moisture level.
[c] Mixing tolerance index.
[d] 1–8 (1 = weak, 8 = strong).

second clear flour, and semolina, the absorption values were higher for the durum wheat samples than they were for the bread wheat flour samples. This finding is consistent with available information (Sandstedt and Schroeder 1960, Pomeranz 1968, Tipples et al 1978, Kunerth and D'Appolonia 1985) and can be attributed to the higher damaged starch content of durum flour (Table IV). The relative water uptake of the major dough components was estimated by Bushuk (1966) to be 0.44 g per gram of granular starch, 2.0 g per gram of damaged starch, 2.2 g per gram of protein, and 15 g per gram of pentosan. The particle size of semolina is an important factor contributing to its lower absorption (Dexter and Matsuo 1978). Durum clear flours, which contain the tail-end flour streams, are high in farinograph absorption because of their high content of damaged starch and pentosans (Holas and Tipples 1978). Different flour grades differ in water absorption (D'Appolonia 1984). Despite the higher absorption values for the durum wheat samples, they showed short-to-medium peak time; the bread wheat flours showed a medium-to-long peak time. The dough development time (peak time) is an indication of protein quality; stronger flours normally require a longer development time than do weaker flours. Therefore, a comparison of peak times indicates the relative strength of different flours (Faridi 1990). Besides protein quantity and quality, the difference in the degree of damaged starch is the most likely factor to affect the rate of hydration (Kunerth and D'Appolonia 1985).

A distinct difference was found in mixing tolerance index (MTI) between the durum and bread wheat flours. The MTI values were lower for all bread wheat flours than they were for the durum flours. The stability values showed the same trend as the MTI values.

A study conducted on durum wheat flours derived from Italian durum cultivars showed significant correlations for bread volume with both farinograph peak time and stability (Boggini and Pogna 1989).

The farinograph classification numbers also differed between the durum and bread wheat flours; higher scores were reported for the bread wheat flour samples.

Mixograph Data

As indicated by Pyler (1988), time-to-peak height differed between the durum and bread wheat flours (short and long mixing times, respectively; Table VII). This value is similar to farinograph peak time values. Thus, factors such as protein quantity and quality and damaged starch, which affect farinograph peak time, are also responsible for differences in mixograph time-to-peak height.

The height of the curve center at the peak varied between the samples. However, lowest and highest values were obtained with durum second clear and untreated bread flour, respectively. Classification number, when incorporated with peak time and overall peak shape, showed a difference between durum and bread wheat flours.

TABLE VII
Mixograph Data[a]

Flour Sample	Time-to-Peak Height (min)	Height of Curve Center at Peak (mixograph unit)	Classification Scale[b]
Durum flour	2.0	6.2	4
Durum first clear flour 1	2.2	4.7	4
Durum first clear flour 2	2.2	6.0	4
Durum first clear flour 3	2.5	3.8	3
Durum second clear flour	3.3	3.3	2
Semolina	3.2	6.2	5
Bakers commercial flour	4.1	5.5	5
Bread flour	3.5	4.0	4
Untreated bread flour	4.0	6.6	6

[a]Values represent the mean of two replicates.
[b]1–8 (1 = weak, 8 = strong).

Extensigraph Data

As shown in Table VIII, there are remarkable differences in dough characteristics between the durum and bread wheat flours. With the exception of the strong, untreated bread flour, the durum flour and semolina samples showed greater extensibility than did the bread wheat flour samples. The bread wheat flours, except for the weak bread flour, displayed higher maximum resistance values than did the durum wheat flours. Proportional number (ratio of maximum resistance to extension) was more variable. Although bakers commercial flour showed the highest proportional number, it should be noted that extensigraph data for this flour was affected by its bromate content.

Extensigraph area data differed between the durum and bread wheat flours. All bread wheat flour samples showed larger values for area under the curve. In general, extensigrams of wheat flour doughs can be categorized into four groups: weak, medium, strong, and very strong. Although the precise numbers are somewhat arbitrary, flours that give extensigrams with areas less than 80 cm^2 can be classified as weak; those with areas of 80–120 cm^2 can be classified as medium; those with areas of 120–200 cm^2 can be classified as strong; and those with areas above 200 cm^2 can be classified as very strong (Preston and Hoseney 1991). According to these classifications, the bread flour and all durum wheat flour samples are weak; the bakers commercial and untreated bread flours are strong.

It is generally accepted that doughs from durum wheat are less elastic than the doughs from bread flour. Durum wheat has a higher gliadin and lower glutenin content, which yields a very

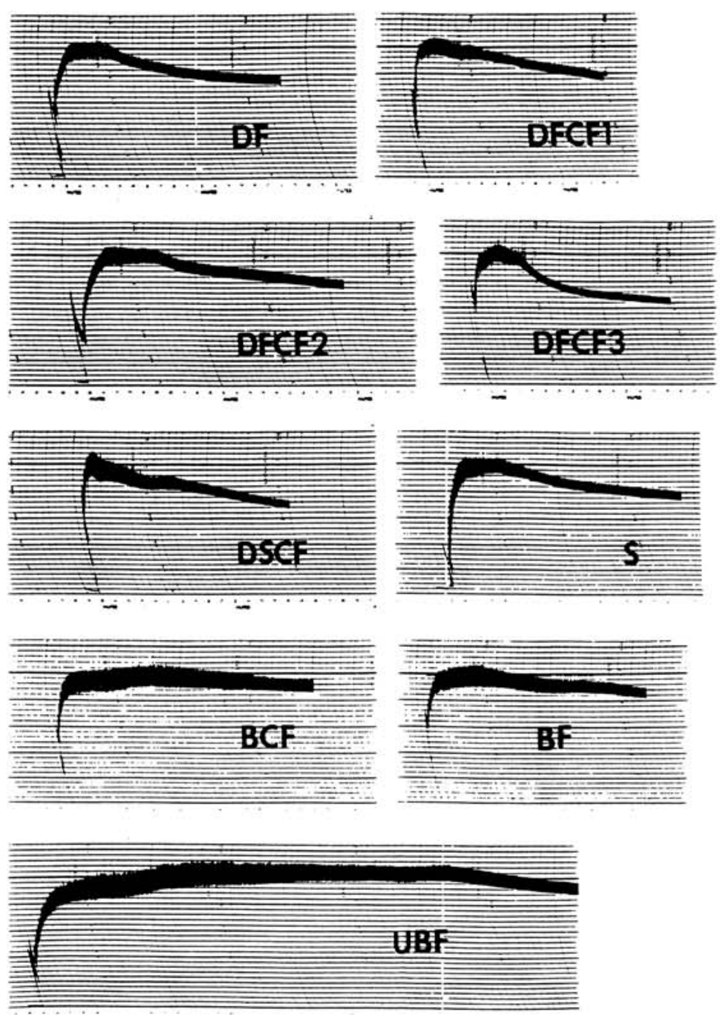

Fig. 1. Farinograms of bread or durum wheat flours. DF = durum flour, DFCF = durum first clear flour (samples 1–3), DSCF = durum second clear flour, S = semolina, BCF = bakers commercial flour, BF = bread flour, UBF = untreated bread flour.

TABLE VIII
Extensigraph Data[a]

Flour Sample	Extensibility, cm 45 min	Extensibility, cm 180 min	Resistance, cm 45 min	Resistance, cm 180 min	Proportional Number at 180 min	Area (cm^2) at 180 min
Durum flour	19.3	15.9	1.6	3.1	0.19	35
Durum first clear flour 1	13.6	11.8	2.8	4.1	0.35	35
Durum first clear flour 2	17.3	15.9	2.7	3.3	0.21	40
Durum first clear flour 3	5.5	NA[b]	0.9	NA	NA	NA
Durum second clear flour	9.2	5.4	1.8	3.3	0.61	18
Semolina	19.0	17.0	2.2	4.1	0.24	49
Bakers commercial flour	22.4	13.4	10.4	13.7	1.02	118
Bread flour	17.8	14.7	2.6	3.4	0.23	53
Untreated bread flour	28.9	24.0	7.8	10.5	0.44	173

[a]Values represent the mean of two replicates.
[b]Not attainable due to extremely weak character of dough.

TABLE IX
Alveograph Data[a]

Flour Sample	Tenacity, P (mm)	Extensibility, L (mm)	Deformation Energy, W (10^{-4} joule)
Durum flour	118	53	220
Durum first clear flour 1	95	42	125
Durum first clear flour 2	106	49	190
Durum first clear flour 3	37	12	15
Durum second clear flour	57	24	50
Semolina	58	36	75
Bakers commercial flour	89	134	400
Bread flour	62	67	120
Untreated bread flour	130	84	490

[a]Values represent the mean of two replicates.

TABLE X
Maturograph Data[a]

Flour Sample	Final Proof Period (min)	Fermentation Stability (min)	Dough Level (BU)	Elasticity (BU)
Durum flour				
Unmalted	32.0	2.5	395	170
Malted	34.0	6.5	390	160
Durum first clear flour 1	32.0	1.0	505	195
Durum first clear flour 2	30.0	4.5	470	200
Durum first clear flour 3	26.0	1.0	240	135
Durum second clear flour	24.5	0.5	285	150
Semolina	34.0	4.5	480	190
Bakers commercial flour	46.0	10.5	620	220
Bread flour	34.5	4.5	460	180
Untreated bread flour				
Unmalted	54.0	4.5	440	155
Malted	48.0	6.5	390	160

[a]Values represent the mean of two replicates.

extensible but less elastic dough (Dick 1981, Matz 1987, Feillet 1988, Milatović and Mondelli 1991). Higher starch damage and absorption values for durum wheat flours might affect their extensigraph characteristics (Farrand 1964, Bloksma and Bushuk 1988, Preston and Hoseney 1991).

Alveograph Data

The tenacity value (P), which is recognized as an indicator of dough resistance to deformation, varied among the samples. Nevertheless, untreated bread flour had the highest P value, and the durum flour sample had the second highest (Table IX). Farrand (1964) and Chen and D'Appolonia (1985) showed that damaged starch affects alveograph values. Water absorption is much greater for damaged starch than it is for intact starch granules, thus increasing the total water-absorption potential of flour. Because the absorption used in the standard alveograph test is held constant, an increase in the damaged starch content of a flour means less water is available for absorption, resulting in higher P and lower L (extensibility) values. Consequently, the W (deformation energy) values also increase (Faridi and Rasper 1987).

The bakers commercial flour displayed the highest L value, although Khattak et al (1974) and Chen and D'Appolonia (1986) demonstrated an increase in P value and decrease in L and W values with the addition of an oxidizing agent in the alveograph test.

Untreated bread flour had the highest W value. With the exception of the weak bread flour, all bread wheat flour samples had higher W values than the durum wheat flour samples. The W value is considered to be closely related to flour strength.

Quaglia (1988) stated that alveograms of durum wheat flours indicate very high tenacity versus elasticity (P/L). Consequently, the P/L ratio is over 1.5, and the work corresponding to the deformation of the dough sample (W) is about 200. A P/L value of 0.8–2.0 for flour was reported to be good for making both pasta and bread (Milatović and Mondelli 1991).

Maturograph Data

This instrument estimates the optimum final proof conditions and fermentation tolerances of a fermented dough by measuring and recording changes in its elasticity (Pyler 1988). Final proof time, the time needed to obtain maximum fermentation maturity, differed between durum and bread wheat flours (Table X). Although final proof time of the bread flour sample was only slightly higher than that of the durum wheat flours, the remaining bread wheat flours had considerably higher final proof times.

Fermentation stability provides the time tolerance for putting the loaf into the oven; it is necessary for obtaining an optimum baking volume. This parameter was highest with bakers commercial flour and lowest with durum second clear flour.

Bakers commercial flour had the highest dough level measurement, which is the maximum resistance of the dough in the maturograph. The dough level refers to the gassing power and gas retention of the dough (Seibel 1968, Pyler 1988). With the exception of this sample, dough level values showed no consistent trend between the durum and bread wheat flours. The bakers commercial flour also had the highest elasticity value among all flours.

For maturograph and oven-rise recorder tests, flour samples should have optimum α-amylase enzyme activity: amylograph values of 300–700 BU (W. Sietz, Brabender OHG, Duisburg, Germany, *personal communication*, 1991). Therefore, the durum flour and untreated bread flour samples were treated with malt flour so that their amylograph peak viscosity values were 555 and 490 BU, respectively. However, no difference was found in maturograph and oven-rise recorder values between flours treated or untreated with malt.

Oven-Rise Recorder Data

The maturograph is generally supplemented by the oven-rise recorder, which measures and records the oven spring of a fermented dough ball heated from 30 to 100°C in 22 min. Dough volume is the value recorded at the beginning of the baking process. End volume is the value recorded for the piece of dough after 22 min of baking. Untreated bread flour had the maximum dough volume and bakers commercial flour had the maximun end volume (Table XI). Oven-rise is calculated as end volume minus dough volume. Durum first clear flour 3 collapsed during baking, as indicated by the negative oven-rise value. The bakers commercial flour displayed maximum oven rise. Final oven rise is the measurement from the middle of the curve after 11 min of baking to the top of the curve after 22 min of baking. It represents the curve of the baked goods in the higher temperature range. The suppression and shrinkage of the baked goods is recorded numerically (Shuey 1975). Again, highest final oven-rise value was demonstrated by the bakers commercial flour. In addition to the bakers commercial flour, the durum flour, semolina, and bread flour showed positive final oven-rise values, whereas the untreated bread flour displayed a negative value.

Bread Properties

The results of the baking evaluation are shown in Tables XII and XIII. The baking properties of durum and bread wheat flours were evaluated with and without an oxidizing agent (potassium bromate). During fermentation, the doughs made from the durum first clear flour 3 and durum second clear flour became sticky and difficult to handle. This problem was more pronounced in the baking formula with 1% salt and no shortening (preliminary baking studies). Incorporating 2% salt alleviated the stickiness.

One would expect the bread wheat flours to give the highest loaf volumes; however, the loaf volume of the durum flour was only slightly lower than that of the weak bread flour sample with no oxidizing agent. For bread baked with an oxidizing agent, the loaf volume of the durum flour was higher than that of the weak bread flour. As expected, the lowest loaf volume was exhibited with the durum second clear flour. In general, adding an oxidizing agent to bread wheat flours resulted in overoxidized characteristics, whereas the added oxidation had a positive effect on the durum flour. For the bakers commercial flour, which was already bromated, the effects of overoxidation were even more pronounced.

All durum wheat flour samples had lower scores for overall external appearance than did the bread wheat flours. Bread made from semolina had a specky crust structure because of its larger particle size. The bread made from the durum flour was similar in external appearance to that of the weak bread flour. Crust color of durum wheat breads was darker than that of the other breads, possibly because of the higher starch damage and total sugar content. The external characteristics of breads baked from durum and bread wheat flours without an oxidizing agent are displayed in Figure 2. No difference was observed in external appearance and crust color with the addition of an oxidizing agent.

The grain and texture of durum wheat breads were coarse, dense, and rough. However, incorporating an oxidizing agent improved the grain and texture of these breads, specifically for the breads made from durum flour and durum first clear flours 1 and 2. Furthermore, the crumb color of bread made from durum flour and semolina appeared yellow, while that of the durum clear flours was yellowish-brown. The crumb color scores showed a positive response to addition of an oxidizing agent. However, because of high xanthophyll content, the yellow color remained

TABLE XI
Oven-Rise Recorder Data (BU)[a]

Flour Sample	Dough Volume	End Volume	Oven Rise	Final Oven Rise
Durum flour				
Unmalted	290	530	240	+60
Malted	320	515	95	−10
Durum first clear flour 1	300	350	50	−110
Durum first clear flour 2	280	320	40	−30
Durum first clear flour 3	220	210	−10	−65
Durum second clear flour	180	215	35	−35
Semolina	275	500	225	+40
Bakers commercial flour	270	555	275	+145
Bread flour	270	470	200	+70
Untreated bread flour				
Unmalted	340	440	100	−20
Malted	330	490	160	−10

[a]Values represent the mean of two replicates.

TABLE XII
Loaf Volume and Evaluation of Bread Baked Without an Oxidizing Agent[a]

Flour Sample	Loaf Volume (cm^3)	Attribute Score[b] External Appearance	Crust Color	Grain and Texture	Crumb Color
Durum flour	640	4.0	10.0	5.0	4.0
Durum first clear flour 1	575	2.0	10.0	3.5	2.0
Durum first clear flour 2	605	4.0	10.0	4.0	3.0
Durum first clear flour 3	445	1.0	8.0	2.0	2.0
Durum second clear flour	420	1.0	7.0	2.0	2.0
Semolina	530	3.0	10.0	4.0	4.0
Bakers commercial flour	800	7.0	10.0	8.0	9.0
Bread flour	670	5.0	10.0	5.0	6.0
Untreated bread flour	855	9.0	10.0	7.0	7.5

[a]Values represent the mean of two replicates.
[b]1–10 (1 = lowest, 10 = highest).

TABLE XIII
Loaf Volume and Evaluation of Bread Baked With an Oxidizing Agent[a,b]

Flour Sample	Loaf Volume (cm^3)	Attribute Scores[c] External Appearance	Crust Color	Grain and Texture	Crumb Color
Durum flour	660	4.0	10.0	7.0	5.0
Durum first clear flour 1	550	2.0	10.0	4.5	4.0
Durum first clear flour 2	580	3.0	10.0	5.5	4.5
Durum first clear flour 3	440	1.0	8.0	2.0	3.0
Durum second clear flour	435	1.0	7.0	2.0	3.0
Semolina	510	3.0	10.0	4.0	5.0
Bakers commercial flour	670	6.0	10.0	8.0	8.0
Bread flour	620	6.0	10.0	5.5	7.0
Untreated bread flour	780	8.0	10.0	8.0	7.5

[a]Values represent the mean of two replicates.
[b]Potassium bromate, 10 ppm.
[c]1–10 (1 = lowest, 10 = highest).

Fig. 2. External appearance of bread baked from bread or durum wheat flours. DF = durum flour, DFCF = durum first clear flour (samples 1–3), DSCF = durum second clear flour, S = semolina, BCF = bakers commercial flour, BF = bread flour, UBF = untreated bread flour.

with the durum wheat breads.

Durum flour rated the best among the durum samples for breadmaking potential. Studies on incorporating bread additives, use of flour blends, and modification in baking procedure will be reported elsewhere.

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