A Comparison of Some Rheological Properties of Durum and Wheat Flour Doughs

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ABSTRACT

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The rheological behavior of doughs made from three commercial blends of wheat flours were compared. Two of the flours were wheat blends suitable for bread baking but milled quite differently. One was milled in the same way as the third, a durum wheat. The durum wheat flour contained 50% more protein than the two wheat blends and had a larger granulation after milling. The doughs were studied at two levels of water addition (35 and 45% mb) and analyzed in oscillation tests, and the elastic modulus and phase angle were measured. It was found that doughs of similar rheological behavior could be obtained from flours differing considerably in protein content by manipulating particle size distribution and damaged starch content. A correlation between the elastic modulus and the amount of damaged starch was found when the level of starch damage was below 10%. The flours analyzed showed fairly good linear viscoelastic behavior when limited strain values were applied and when the changes in the applied strain values with time were limited.

The major use of durum wheat is for pasta production. However, in regions that supply almost half of the world production of durum wheat (the Near and Middle East and North Africa), durum wheat is also used for baking bread. As much as 50% of durum production is used for local breads in the Middle East and North Africa (Bozzini 1988).

One large difference between the industrial production of pasta and bread is the moisture content of the dough. The total water content of a wheat flour dough for bread baking is around 45%. This amount is decreased to around 35% water content for durum wheat in pasta production. There are also chemical and physical differences between durum wheat and wheat flour of good baking quality (Toepfer et al 1972, Moss 1973).

The methods for rheological characterization of wheat flour doughs for baking purposes have been under constant development during the last few decades (Hibberd and Wallace 1966; Hibberd 1970a,b; Smith et al 1970; Funt Bar-David and Lerchenthal 1975; Abdelrahman and Spies 1986). The expression of rheological values in fundamental units, such as the elastic modulus (G′), the viscous modulus (G″), or the relaxation modulus (G), makes the results from different studies comparable. Both the sensitivity (use of small strains) and the accuracy (expressed as high reproducibility) have been improved. Still, the pretreatment of the dough must be reproducible; the mixograph and the farinograph are excellent tools for this purpose. Several works have shown the relationship of G′, G″, and G to wheat varieties, water content, mixing time, etc. (Hibberd and Parker 1975, Bohlin and Carlson 1980, Nawickis et al 1982, Lindahl and Svensson 1988). However, little work on the rheological behavior of durum wheat doughs has been reported. The present investigation was undertaken to describe the rheological differences between durum and other wheats. The influence of high pressure, which is used in industrial production of pasta, is not considered in this study. The mixing procedure of such a full-scale pasta production can be difficult to imitate in laboratory when only a few grams of dough are used. Wheat flour of standard baking quality was compared with a durum wheat flour and a wheat flour of standard baking quality milled with exactly the same milling procedure as used on the durum wheat. Therefore, differences that occurred in particle size distribution were due to the physical character of the grains. Different flour streams from the durum wheat milling were also used for rheological characterization. The elasticity of doughs of durum and other wheats in relation to water content was measured in oscillation tests, and correlations between the rheological parameters and particle size distribution and damaged starch were investigated.

MATERIALS AND METHODS

Flour

The durum and wheat flours were supplied by NordMills (Malmö, Sweden). The wheats were commercial blends of different cultivars. The wheat flour was of Swedish standard baking quality (BW). The durum wheat (DW) was milled for pasta production with a granulation of 68.6% larger than 132 μm. This means that the DW can be called granular flour (Matsuo 1988). The third flour (DB) was ordinary wheat milled as a durum wheat. The BW and DB flours were composed of different blends to give similar chemical composition. Both the single DW flour and the DB wheat flour in mixtures with the DW flour are used in commercial production of pasta products in Sweden. Analytical data are shown in Table I. Different flour streams from the durum milling were also used. A–E, H, and I were from the break system; F and G were from the reduction system.

Dough Mixing

Doughs were mixed in the small bowl of a farinograph (Brabender DoCorder) at 30°C and at two different water levels. To simulate the dough making in industrial pasta production, 10 g of flour was mixed with 3.5 ml of tap water (i.e., 37% moisture in the dough). The small bowl of the farinograph was covered with a lid just above the mixing blades when 3.5 ml of tap water was used. This was done to obtain a cohesive dough structure suitable for measuring in the rheometer. Mixing time was 4 min. Doughs corresponding to a breadmaking procedure were mixed from 10 g of flour and 5.5 ml of tap water (i.e., 45.2% moisture in the dough). Mixing time was 8 min unless otherwise indicated. Rheological measurements were done on 0.5 or 1.0 g of dough, depending on the measuring system used. All doughs were analyzed immediately after mixing except when a time-dependent study of DW and DB was performed. The doughs were then wrapped in a plastic film and stored at room temperature.

Rheological Measurements

The Bohlin rheometer system (Bohlin Reologi, Lund, Sweden)

TABLE I
Analytical Data for the Flours Studied
(Results Based on 15% Water Content)

	Flours[a]		
	BW	DB	DW
Protein, %	10.0	9.9	15.3
Ash content, %	0.55	0.50	0.87
Falling number	305	348	513
Damaged starch, %[b]	9.9	5.8	8.2

[a] BW = wheat flour of Swedish standard baking quality, DB = ordinary wheat milled as a durum wheat, DW = durum wheat.
[b] AACC Method 76-30A (AACC 1983).

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was used in oscillation and strain sweep tests. In oscillation tests, two types of measuring systems were necessary, depending on the stiffness of the dough. One gram of dough was used in the cone-and-plate (CP) system. The angle of the cone was 5.4°, and the diameter of the CP system was 30 mm. The gap between cone and plate during measurement was 150 μm. For doughs with the low moisture content (37%), a plate-and-plate (PP) system was used (15 mm in diameter). The gap between the plates was 1 mm during measurement; 0.5 g of dough was used. The temperature was 25°C for all measurements. All measurements were repeated at least twice on independently prepared doughs. The strain sweep test was performed as an oscillatory measurement at a fixed frequency (0.2 Hz in this case), with an increasing strain. The strain was applied at 0.5×10^{-3} and upward in steps of this magnitude.

The frequency in the oscillation test was varied from 0.02 to 5.0 Hz. The strain value was 5×10^{-3} when the PP system was used and 9×10^{-3} when the CP system was used. The elastic modulus (G′) and phase angle (δ) were used to characterize the doughs. The phase angle is defined as $\tan \delta = G''/G'$, where G″ is the viscous modulus. The phase angle is 0° for a completely elastic material and 90° for a completely viscous material. Thus, a viscoelastic material shows values of 0–90; values around 30° have been reported for a wheat flour dough (Abdelrahman and Spies 1986).

The doughs were allowed to equilibrate 60 sec before the strain was applied. Equilibration time was based on the relaxation time for a wheat flour dough, which is around 1 sec (Bohlin and Carlson 1981). Longer delay times were not acceptable since a time-dependent function can be studied only when freshly made doughs are available for measurement. Of course, the pretreatment of the dough is relevant to the rheological values obtained. However, earlier experiments showed acceptable variation (i.e., less than 10%) in the relaxation modulus G or the elastic modulus G′ under these experimental conditions.

RESULTS AND DISCUSSION

The particle size distributions of DB and DW were dominated by relatively large particles (Fig. 1). The fractions above 132 μm corresponded to 68.6% of the durum wheat flour. The particle size distribution of the DB flour was shifted towards smaller particles, with 38.4% of the flour above 132 μm. The size distribution of the BW flour was characterized by small particles; 53.8% was less than 85 μm, 27.6% was 85–112 μm, and 15.7% was 112–150 μm. Only 2.9% was larger than 150 μm. The particle size distributions for DB and DW were quite different despite an identical milling process. The softness of the DB kernels gave a smaller granulation than the harder durum wheat. The hardness of the kernels and the resulting particle size distribution were also responsible for a higher degree of damaged starch in the DW than in the DB flour (Table I).

When the particle size distribution by the milling procedure was shifted towards smaller particles in the flour streams, the content of damaged starch in streams E–I increased (Table II). Flour streams with most of the flour particles smaller than 132 μm had a damaged starch content of 14–17% compared with the final DW, which had 8.2% damaged starch. The two flours DB and BW were similar in protein and ash but not in level of starch damage, which was 5.8% in DB and 9.9% in BW. DW had higher protein and ash contents and a level of damaged starch between that of BW and DB. The flour streams of DW that had most of the granulation below 132 μm had the highest content of damaged starch. Flour stream I was an exception, with a small amount of flour extractable from the bran section of the kernel.

The doughs from DB and DW were first compared in a strain sweep test (Fig. 2). According to other researchers (Hibberd and Wallace 1966, Smith et al 1970, Hibberd and Parker 1975, Nawickis et al 1982), it is doubtful that any region of linearity could be found when a wheat dough is exposed to increasing strain. It has been shown that the linearity depends on the wheat variety, the mixing procedure, and the test technique used (Faubion et al 1987). To approach the conditions used during pasta production, the flours of DW and DB were mixed with only 3.5 ml of water (37% mb) for a short time (4 min). Under these conditions it was not possible to mix the BW into a dough that could be used for reliable rheological characterization. On the other hand, there was no tendency to find a linear region

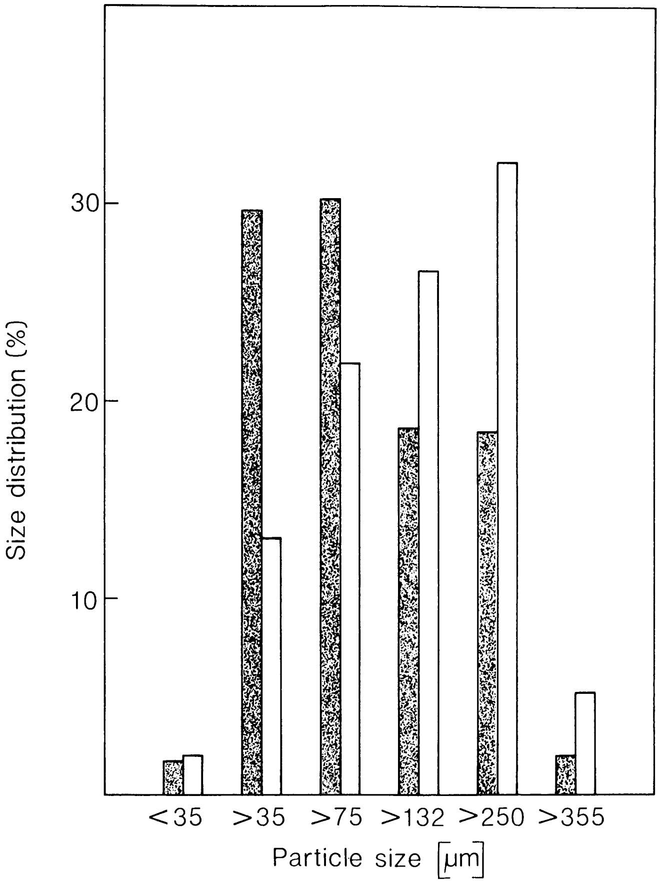

Fig. 1. Particle size distribution of flours from durum wheat (open bars) and ordinary wheat milled as a durum wheat (filled bars).

TABLE II
Chemical and Physical Data for the Flours Studied (Results Based on 15% Water Content)

	Flours[a]									
	DW	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Protein, %	15.3	14.1	14.0	14.3	15.2	15.9	14.7	18.5	16.2	22.0
Ash content, %	0.87	0.62	0.61	0.68	0.76	1.21	0.71	1.39	1.48	2.50
Falling number	513	528	434	481	482	480	485	490	474	419
Damaged starch, %[b]	8.2	7.4	4.6	5.2	4.8	15.5	14.7	16.3	16.6	10.7
Particle size > 132 μm, %	68.6	75.5	96.6	96.7	97.3	8.7	13.4	4.3	3.0	5.0
Phase angle, degrees at 5.0 Hz	33	32	32	34	34	29	28	29	31	38

[a] DW = durum wheat, A–I = flour streams from the durum milling.
[b] AACC Method 76-30A (AACC 1983).

with the low water content (37% mb) in the BW dough. But the BW dough was also far from the optimum treatment for the best loaf of bread (i.e., mixing with 5.5 ml of water for 8 min). Evidently, BW gave much stiffer doughs than either DB or DW at the low water content. However, BW showed good linearity at the high water content (45% mb) below a strain of 0.0095 (not shown).

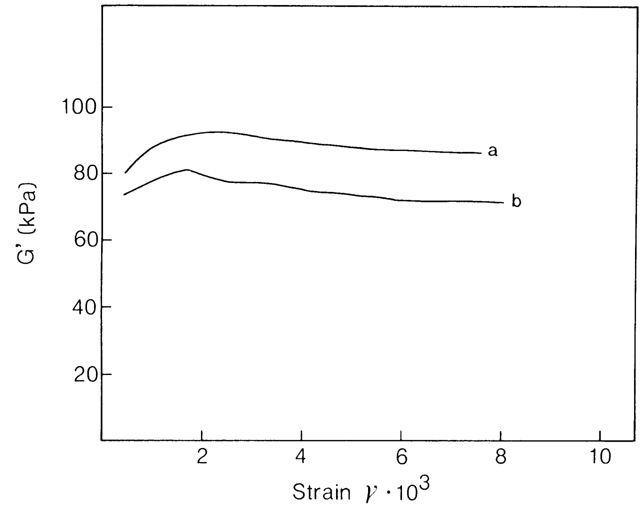

Fig. 2. Strain sweep test. The values for the elastic modulus (G′) were measured at 0.2 Hz as a function of increasing strain (γ). a = durum wheat (phase angle, 28.4°); b = ordinary wheat milled as a durum wheat (phase angle, 28.8°). The doughs were mixed with 3.5 ml of water for 4 min; the phase angle was calculated as an average value during the test for the different flours.

The results in Figure 2 should be interpreted with a few comments. To achieve what looks like a fairly good linearity, the change in step length of the applied strain was crucial. When the magnitude of the strain steps was above 5×10^{-4}, it was not possible to find any region of linearity. With the measuring technique used, the wheat doughs seemed to behave as a three-dimensional uniform structure. This means that no rheological changes (depending on specific orientation in the material) occurred, as long as the strain was below 0.008. This could be interpreted as measurements in which the induced forces are nondestructive. This leads to a reversible process in terms of molecular extension.

For testing the flours at high water content (corresponding to doughs for breadmaking), 10 g of flour was mixed with 5.5 ml of water (45.2% mb) for 8 min. The doughs were analyzed in oscillation tests (Fig. 3). The G′ value was very similar for the DW and the DB doughs during the frequency sweep, whereas the value for the BW dough was about 35% higher. During handling of the doughs after mixing and before the oscillation test, it was observed that they had quite different consistencies. The BW dough could be regarded as having the "right" viscoelasticity, since the treatment was in accordance with doughs for breadmaking (Hammam et al 1988). The DB and the DW doughs were much stickier. The average phase angle, which may be associated with sticky behavior, gave the highest value for the DB dough (δ = 41.7°). The DB dough could also be classified as the stickiest dough during handling.

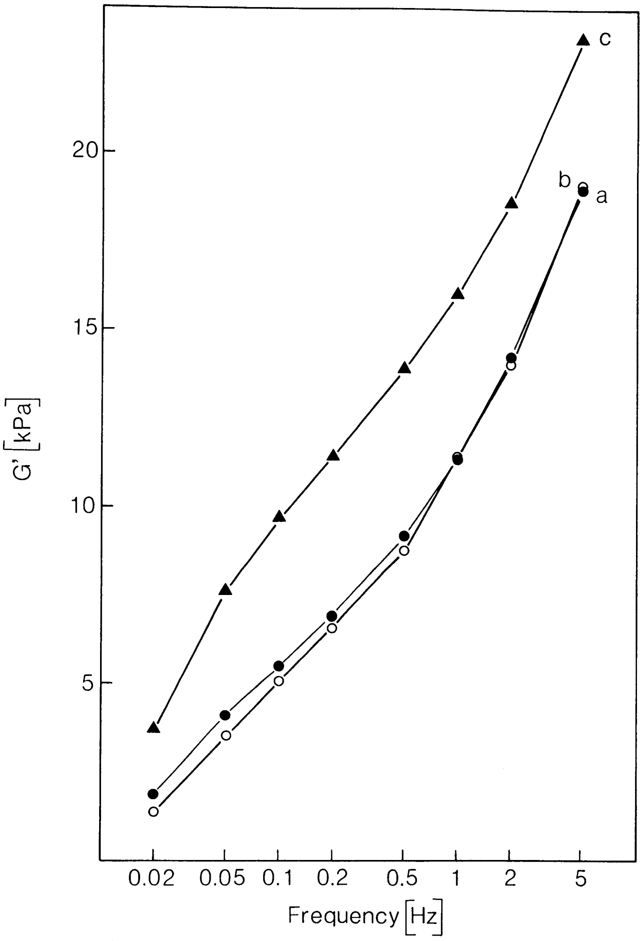

Fig. 3. Elastic modulus (G′) vs. frequency. a = durum wheat (phase angle, 34.4°); b = ordinary wheat milled as a durum wheat (phase angle, 41.7°); c = wheat flour of Swedish standard baking quality (phase angle, 30.5°). The doughs were mixed with 5.5 ml of water for 8 min; the phase angle during the measurement is an average value. The cone-and-plate system was used with an applied strain of 9×10^{-3}.

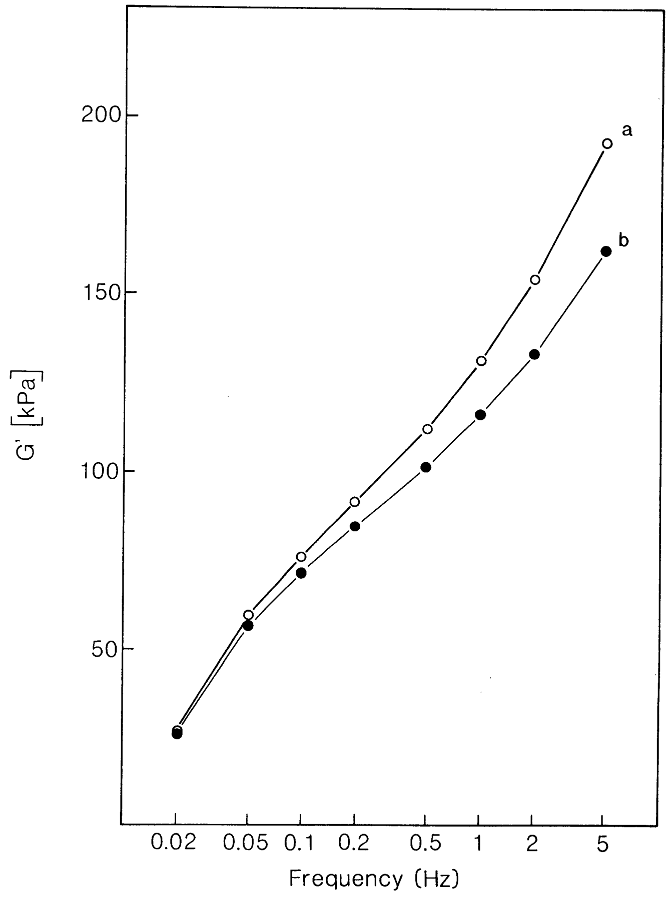

Fig. 4. Elastic modulus (G′) of doughs from durum wheat and ordinary wheat milled as a durum wheat vs. frequency. a = durum wheat (phase angle, 29.6°); b = ordinary wheat milled as a durum wheat (phase angle, 29.6°). The doughs were mixed with 3.5 ml of water for 4 min; the phase angle during the measurement is an average value. The plate-and-plate system was used with a strain of 5×10^{-3}.

The water content was then changed to 37% in the doughs and mixing time was reduced to 4 min. The DW and DB doughs were similar both in G′ values and phase angle (Fig. 4). The phase angle decreased to about 30°, a value in agreement with an optimized wheat flour dough for breadmaking similar to the BW in Fig. 3. The values of G′ and δ from the oscillation test in Figure 4 were very similar to the values from the strain sweep test (Fig. 2). When the water addition was decreased to 37% mb, together with a shorter mixing time (4 min), the DB and DW doughs had a firmer consistency. Both the G′ values and the phase angle (around 30°) showed this. Although the DB flour had two thirds the protein content of the DW flour, the doughs showed very similar rheological behavior. The results in Figure 4 show that it is possible to find mixtures between bread and durum wheats that give doughs with rheological properties similar to those of the pure durum dough.

The rheological properties of the different flour streams, expressed as G′ changed in an irregular way when the level of damaged starch was above 10% (Fig. 5). This emphasizes the importance of the particle size distribution together with the content of damaged starch in determining the rheological behavior of a dough. The main particle size of flour streams F and G was 82% and 64%, respectively, and 75–132 μm. These two flour streams gave doughs with the highest G′ values.

The results in Figure 5 show a correlation of 0.79 between the amount of damaged starch and G′. When the damaged starch content was below 10%, the correlation coefficient increased to 0.83. Similar behavior also could be concluded from Figure 3. The dough with the highest value of damaged starch (9.9% in BW) also gave the highest G′ value. Of course, the amount of water available is responsible for the extent of the cold swelling of damaged starch (Pomeranz 1988). Therefore, the amount of water and its distribution are very important during the mixing process. Doughs with a smaller particle size and a higher degree of damaged starch require more water to maintain a desired viscoelasticity. The G′ values of the DB and the DW doughs in Figure 3 were very similar, but the phase angle showed a clear discrepancy (DB, 41.7°; DW, 34.4°). The increased phase angle was indicative of a stickier dough.

A change in G′ after mixing the dough has been described for some wheat varieties (Lindahl and Svensson 1988). A decrease in G′ with time after mixing, or a constant value, has been found only for doughs made from a single wheat variety. An increase in G′ with time is commonly found both for single varieties and blends. The G′ values of the DB and DW doughs increased with time to the same extent (Fig. 6). The change in G′ values with time was further followed in several batches of DW doughs for 25 min (Fig. 6). It was found that the G′ value reached a plateau after about 20 min of storage at room temperature. Whether these changes in G′ can benefit or influence the quality of the pasta produced remains to be further investigated. An increased G′ value might also affect the extrusion process. In wheat varieties of baking quality, increasing G′ values with time is associated with fairly high protein content of the flour even when the doughs are mixed to optimum (Lindahl and Svensson 1988). This observation indicates that the phenomenon should be general for durum varieties since they are normally high in protein.

CONCLUSION

The particle size of milled wheat is very important for water-absorbing capacity and level of damaged starch. The particle size distribution curve, together with the values for damaged starch,

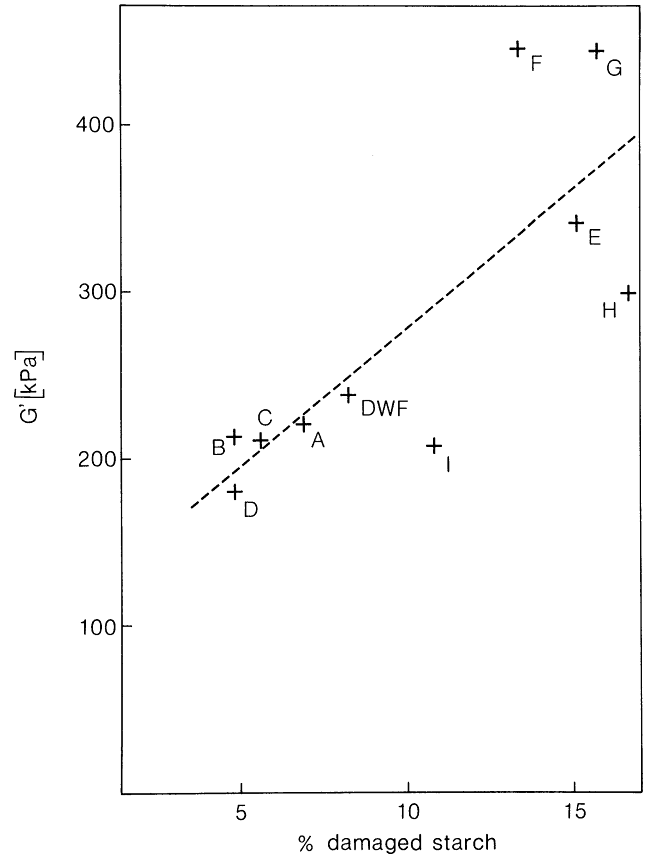

Fig. 5. Elastic modulus (G′) at 5 Hz as a function of damaged starch (AACC Method 76-30A) (AACC 1983) in the durum wheat and in the different flour streams from durum wheat (correlation factor r = 0.79, r^2 = 0.62). The flour fractions (A–I) are described in Table II; the rheological values are average values measured 10–25 min after mixing.

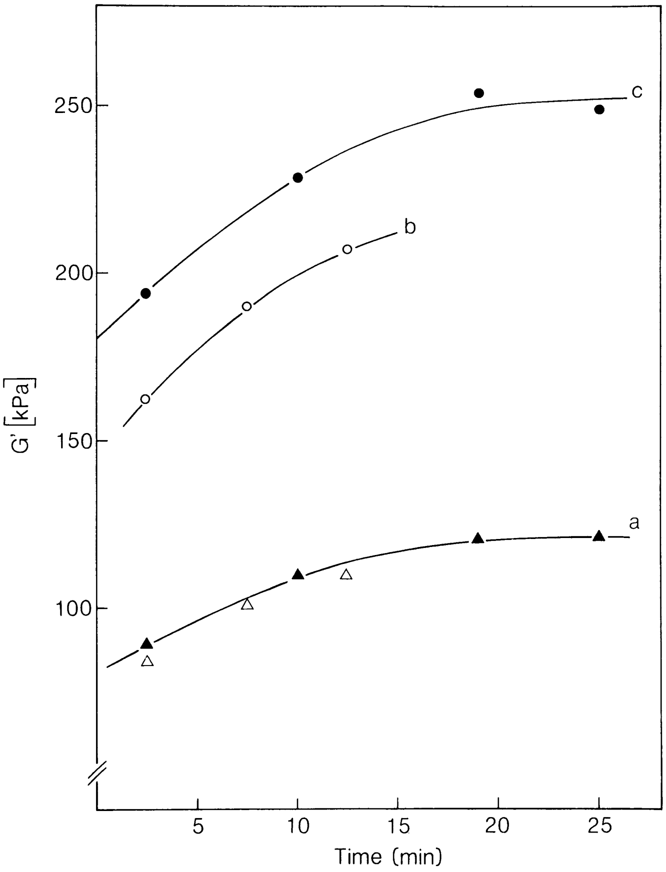

Fig. 6. Change in elastic modulus (G′) vs. time for the doughs from durum wheat (DW) and ordinary wheat milled as a durum wheat (DB). a = DW (0.2 Hz), b = DB (5.0 Hz), c = DW (5.0 Hz). The open triangles below line "a" indicate the DB dough at 0.2 Hz. The increase in G′ is given at two frequencies—5.0 Hz and 0.2 Hz; the latter frequency is identical to that used in the strain sweep test. The plate-to-plate system was used with a strain of 5×10^{-3}.

can give valuable information about viscoelastic behavior at a certain level of water addition. In this case, the small particle size in the DB flour, combined with a low value of damaged starch (5.8%), can be compared with the large particles and higher value of damaged starch (8.2%) in the DW flour. These two flours have identical rheological values in spite of the difference in protein content. The opposite was observed with the flour streams from durum milling. The rheological qualities could be related to particle size and damaged starch, whereas the protein content was similar in the flour streams compared. This emphasizes the importance of the milling process and how it can be used to produce a desired flour quality. At high levels of water addition, differences in the quality of durum and other wheats was observed in that a higher phase angle was obtained for the wheat dough. Therefore, better knowledge of the water distribution is necessary, since it seems possible to obtain doughs with linear behavior. Dough stiffness seemed to depend on the available water and the level of damaged starch.

The gluten structure could be regarded as giving the dough a rheological base level. However, the higher protein content in the durum wheat should be superior to the common baking wheat from this point of view. By manipulating the water content, particle size distribution, and level of damaged starch, it is then possible to influence the rheological values obtained as a result of mixing. Since the examined flours were commercial blends of different cultivars, the result could be regarded as more general than analysis of pure wheat varieties with large inherent discrepancies.

ACKNOWLEDGMENT

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