Use of a Kramer Shear Cell to Measure Cracker Dough Properties[1]

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ABSTRACT

A method was developed to measure the physical properties of cracker doughs using a Kramer shear cell on an Instron universal testing machine. Peak force appears to measure dough stiffness and shoulder force appears to be a function of elasticity or dough development. Doughs from flours that varied in cracker-baking quality had different absolute force values and values that varied with increased fermentation time. With a flour giving crackers with low stack height and weight, shoulder force values initially increased, then decreased with greater sponge fermentation times. With flours giving high stack height and weight, shoulder force value continued to increase during fermentation. These results support previous findings suggesting the importance of proteolytic activity during sponge fermentation, which results in decreased strength of the sponge.

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A major problem encountered in the commercial production of soda crackers is the variation in quality of cracker flours. Flours of similar chemical composition may result in finished products of various qualities. In a report on testing of soft wheat flour, Dunn (1930) stated that "far too little is known of the type of flour best suited to the needs of the biscuit and cracker industry." This statement is still true today.

As early as 1924, Johnson and Bailey reported in their classic work that the extensibility of a fermented cracker sponge in a Chopin Extensimeter decreased rapidly after 6 hr. Several studies using the extensigraph have shown that rheological properties of a cracker sponge—specifically, resistance to extension and decrease in extensibility with fermentation time—change drastically during fermentation (Pizzinatto and Hoseney 1980a, Doescher and Hoseney 1985a, Wu and Hoseney 1989). It also has been shown that these changes are not brought about simply by the decrease in pH. A decrease in pH of the dough to about 4.1 is believed to be optimum for the native flour proteases. Wu and Hoseney (1989) suggested that cracker flour quality depends upon the activity of these proteases.

The purposes of this investigation were to understand how the physical properties of finished cracker doughs changed with fermentation time, water absorption, and formula changes. A method was developed to measure these properties with a Kramer shear cell (KSC). The KSC results were then related to finished cracker characteristics. This approach differs from recent studies in which the properties of the fermented sponges were analyzed.

MATERIALS AND METHODS

Materials

Properties of the flours used are described in Table I. Commercial cracker flours A through F were supplied by ConAgra Flour Milling Co., DCA Food Industries, Inc., Dixie-Portland Flour Mills Inc., Mennel Milling, Co., and Nabisco Brands, Inc. The flours were purported to be their standard cracker flours. Flour X was a hard wheat flour milled at the Kansas State University pilot mill. The other hard flours were obtained from commercial mills. A low-protein hard wheat flour was requested. Red Star compressed yeast was obtained from Universal Foods (Milwaukee, WI). Crisco hydrogenated vegetable shortening was used (Procter & Gamble, Cincinnati, OH). Salt and sodium bicarbonate were supplied by Nabisco Brands. All other chemicals were reagent grade.

Dough Preparation

Cracker doughs were made using a sponge and dough procedure (Pizzinatto and Hoseney 1980b, Doescher and Hoseney 1985a, Rogers and Hoseney 1987). The prefermented slurry (inoculum) was as described by Doescher and Hoseney (1985b). All doughs were made at optimum absorption, unless otherwise noted. Optimum cracker absorption was determined using the mixograph procedure developed by Rogers and Hoseney (1987).

The sponges were made by first blending the yeast, inoculum slurry, and water in an Oster mini-jar for approximately 30 sec and adding the mixture to the sponge flour in the mixing bowl. Mixing was performed in a pin mixer (TMCO-National Mfg. Co., Lincoln, NE) at 32 rpm. Sponges were mixed for a total of 3 min and then fermented for 18 hr (unless specified otherwise) at 27°C.

The pH and total titratable acidity (TTA) of the sponge were measured as described by Rogers and Hoseney (1987). The TTA values were used to calculate the amount of soda necessary to neutralize the acid in the sponge and to give a mixed dough pH of 7.0–7.5. The soda, salt, and remainder of the flour were added to the sponge and mixed for 20 sec. Melted shortening then was added with an additional 10 sec of mix time. The bowl was scraped, and the dough mixed a final 1 min. The dough was then given a 4-hr rest time (unless otherwise specified) at 27°C.

Laboratory Cracker Baking

The dough was sheeted with a modified pizza sheeter (Colborne Mfg. Co., Glenview, IL) to a final roll gap of 0.30 mm (modified by replacing the motor with one that could be run at different speeds; 85 rpm was used here). The dough was cut using a laboratory cutter-docker (Pizzinatto and Hoseney 1980b).

Crackers were baked in an electric reel oven with the shelves held stationary. Details of the procedure are given by Rogers and Hoseney (1987). Crackers were baked at 287°C for 3.25–3.75 min depending on the dough thickness and the cracker color development. Ten crackers from each sheet of 21 were selected and weighed to obtain stack weight, which was reported on a 0% moisture basis. The same crackers were measured for thickness, or stack height, using a dial caliper.

Four crackers from each baked sheet were selected randomly for moisture analysis and ground together in a mortar and pestle to a uniform fineness. Moisture determinations were made in duplicate (AACC 1985). The moisture was used to calculate the starch weight on a dry basis.

KSC Test

The physical properties of the finished cracker doughs were determined using a KSC attachment (Kramer et al 1951) for the Instron universal testing machine.

The final pass of the dough through the sheeting rolls was at a machine gap setting of approximately 2.8–2.9 mm, giving a dough piece with a final thickness of 4.8 ± 0.2 mm. Immediately

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after sheeting, parallel lines, approximately 2–2.5 cm apart, were lightly drawn on the dough sheet with a felt tip marker in the direction of sheeting. Thus, the sheeting direction could be determined on a small sample piece for proper orientation of the piece in the KSC.

Sheeted dough was given a 3-min rest time before thickness measurement and KSC testing. Thickness was measured, and a 29-mm diameter cutter was used to cut three test samples from each cracker dough sheet. Another piece of the original dough was then sheeted and tested as a duplicate of the first.

The KSC test was performed with the 50-kg load cell on the Instron. Crosshead speed was 5 cm/min, and chart speed was set at 10 cm/min.

Each sample was then placed in the center of the KSC cell with the felt marker line running diagonally across the holder, i.e., from one corner to the other. This procedure, with the blades diagonal to the direction of sheeting, was found to give the most reproducible results. The Instron curve was then generated as the blades pushed the dough piece through the bottom slits of the cell.

The curve characteristically had two peaks (Fig. 1): the first was generated as the dough was contacted by the blades; the second, termed the shoulder, was the result of the dough being pushed through the slots with a shearing action by the blunt blades. Average peak and shoulder forces were determined from six sample pieces of each dough.

TABLE I
Analytical Data of Flours

Flour	% Moisture	% Protein (14% mb)	% Ash (14% mb)
Commercial cracker flours[a]			
A	12.5	8.8	0.43
B	11.4	8.8	0.49
C-I	13.7	9.2	0.44
D-I	13.4	8.6	0.43
E	13.4	8.7	0.50
F	12.2	9.3	0.42
Hard wheat flours			
T	13.9	7.7	0.42
U	14.7	9.6	0.36
V	13.3	9.1	0.45
W	14.5	9.1	...
X	13.8	10.2	0.46

[a] All soft wheat flour except for C-I, which was a blend of soft and hard wheat flours.

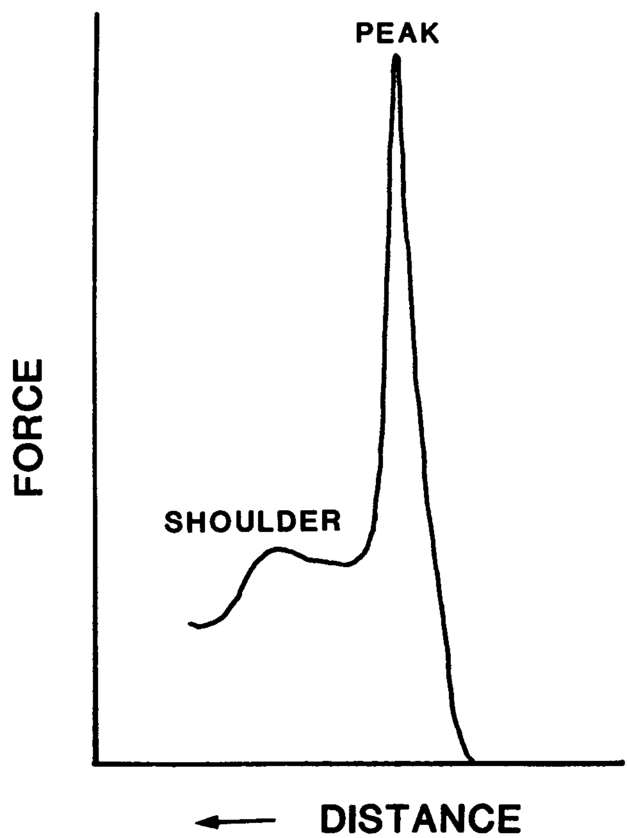

Fig. 1. A typical force vs. distance curve for cracker dough in the Kramer shear cell.

Studies Using the KSC

A series of experiments was undertaken to determine the usefulness of the KSC procedure. First we studied the effect of absorption. Using a series of flours with absorption values spanning the optimum absorption, full-formula yeast-fermented cracker doughs were tested. Sponges were fermented 18 hr, and the dough time was held constant at 4 hr.

In the second experiment, sponge composition and fermentation times were varied. Sponges were made from flour and water only, flour, water, and yeast, or flour, water, yeast, and slurry inoculum (control). The sponges were fermented for various times. After fermentation the sponges were added to the necessary soda and additional ingredients and mixed to a dough. All doughs were tested after 4 hr.

In the third experiment, yeast and slurry were not added to the sponge. Lactic acid was added to the flour and water to immediately decrease the pH to 3.9. The necessary amount of acid was added to the dough water. As before, the sponge was mixed for 3 min. The pH of the sponge was determined immediately after mixing. After the required "fermentation," each sponge was sampled, tested for pH and TTA, and then mixed

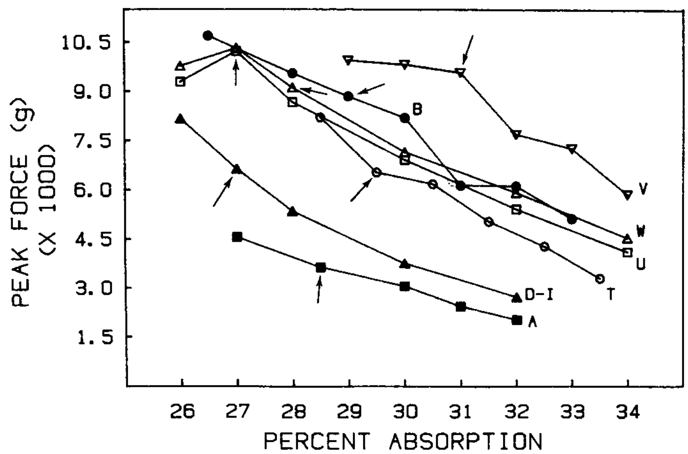

Fig. 2. Peak force as a function of absorption for cracker dough from several flours. The arrows indicate optimum absorption.

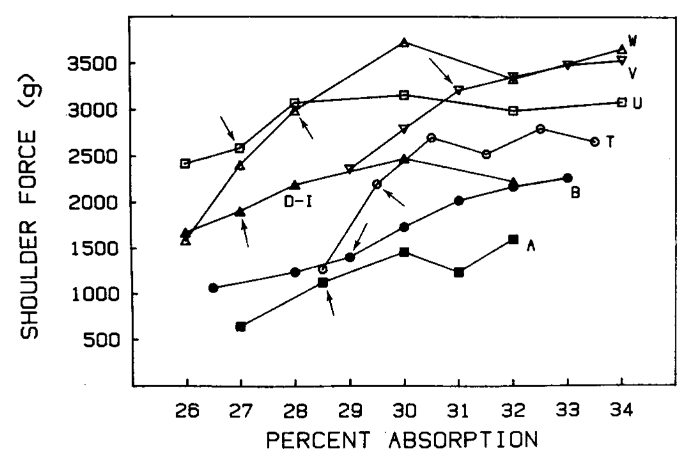

Fig. 3. Shoulder force as a function of absorption for cracker doughs from several flours. The arrows indicate optimum absorption.

with the necessary soda and additional ingredients to form the dough. All doughs were tested after 4 hr.

In a fourth experiment, a series of flours of known cracker-baking quality was used. The full formula was used but sponge fermentation times were varied from 0 to 18 hr. Dough time was held constant at 4 hr. The KSC forces were determined on the doughs.

RESULTS AND DISCUSSION

KSC Forces Versus Absorption

Several hard and soft wheat flours were used to measure the effect of absorption on the KSC peak and shoulder forces. For some flours, water absorption values of 1% below optimum absorption gave a dough that could not be sheeted because it was too dry and crumbly.

Peak and shoulder forces for the soft and hard wheat flour doughs are shown in Figures 2 and 3, respectively. The force at optimum cracker absorption for each flour is shown with an arrow. Peak force decreased for all flours as absorption increased, with all doughs showing essentially the same rate of decrease. Doughs from hard wheat flours (T–X) gave higher peak forces than doughs from soft wheat flours (A, B, and D-I) throughout the absorption range, except for the dough from soft flour B. Doughs from flours A and D-I gave low peak forces. Obviously, peak force decreased with increased absorption because of the softening effect of increased water content. Flours from hard wheats gave higher peak forces than soft wheat flours because of the stronger, more elastic nature of the doughs.

Shoulder force values increased with absorption to a certain point and then leveled off. This leveling off may result from the offsetting effects of 1) dough hydration and development increasing shoulder force and 2) dough hydration increasing the softness of the dough and, thereby, decreasing the shoulder force. Generally, doughs from hard wheat flours (T–W) gave shoulder forces significantly higher than those from soft wheat flours at optimum absorption. This was presumably a result of the strength and elasticity of the hard wheat flour doughs. We believe peak force measures the stiffness of the dough, i.e., the resistance of the dough to the blades pushing through it. The shoulder force appears to be a function of elasticity, extensibility, dough development, and possibly stiffness. The shoulder measures a

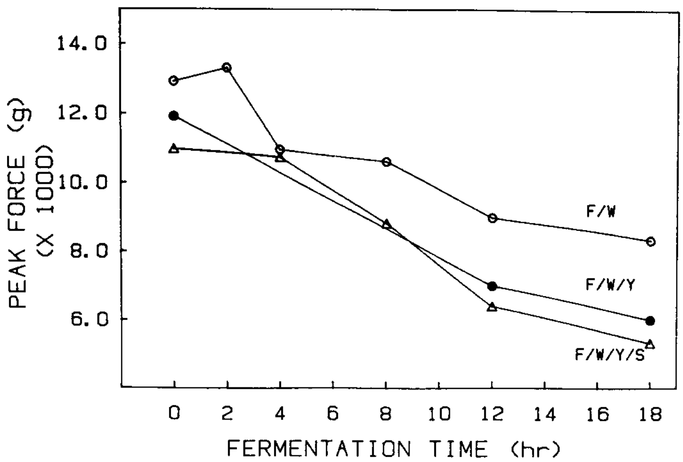

Fig. 4. Peak force as a function of fermentation time for a series of formulations: F/W is flour and water; F/W/Y is flour, water, and yeast; and F/W/Y/S is flour, water, yeast, and slurry. Standard deviations ($n = 6$) for the measurements are as follows: F/W = 1,010, 382, 680, 842, 876, and 666, respectively, at 0, 2, 4, 8, 12, and 18 hr. F/W/Y = 585, 291, and 286 at 0, 12, and 18 hr. F/W/Y/S = 416, 742, 761, 672, and 160 at 0, 4, 8, 12, and 18 hr.

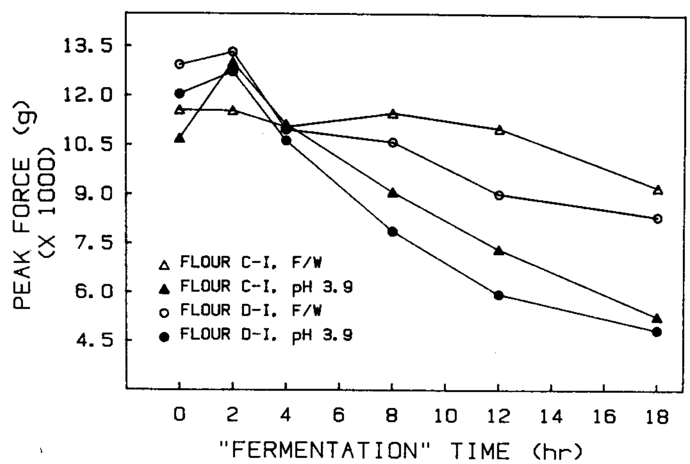

Fig. 6. Peak force of cracker doughs as a function of "fermentation" time for flour-water (F/W) sponges and F/W sponges adjusted to pH 3.9 with lactic acid. Standard deviations ($n = 6$) for the measurements at 0, 2, 4, 8, 12, and 18 hr, respectively, are as follows: flour C-I (F/W) = 977, 715, 413, 965, 555, 652; flour C-I (pH 3.9) = 1,036, 346, 943, 361, 405, 276. Flour D-I (F/W) = 1,010, 382, 680, 842, 876, and 666; flour D-I (pH 3.9) = 1,201, 854, 637, 456, 279, and 289.

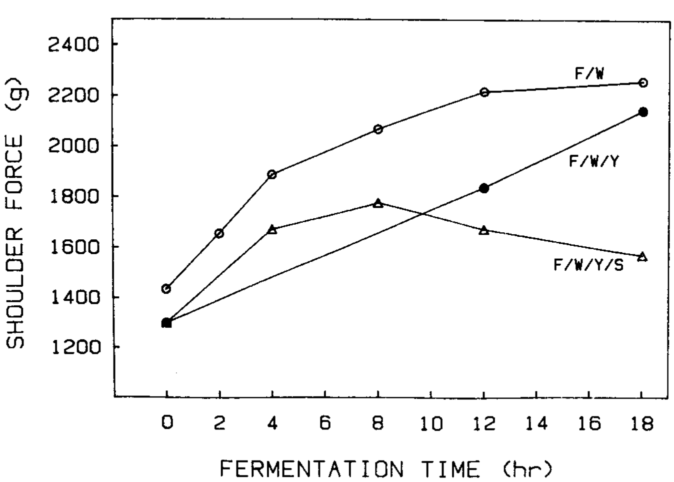

Fig. 5. Shoulder force as a function of fermentation time for a series of formulations: F/W is flour and water, F/W/Y is flour, water, and yeast; and F/W/Y/S is flour, water, yeast, and slurry. Standard deviations ($n = 6$) for the measurements are as follows: F/W = 196, 217, 264, 82, 319, and 218, respectively, at 0, 2, 4, 8, 12, and 18 hr. F/W/Y = 160, 108, and 139 at 0, 12, and 18 hr. F/W/Y/S = 0.0, 175, 164, 248, and 234 at 0, 4, 8, 12, and 18 hr.

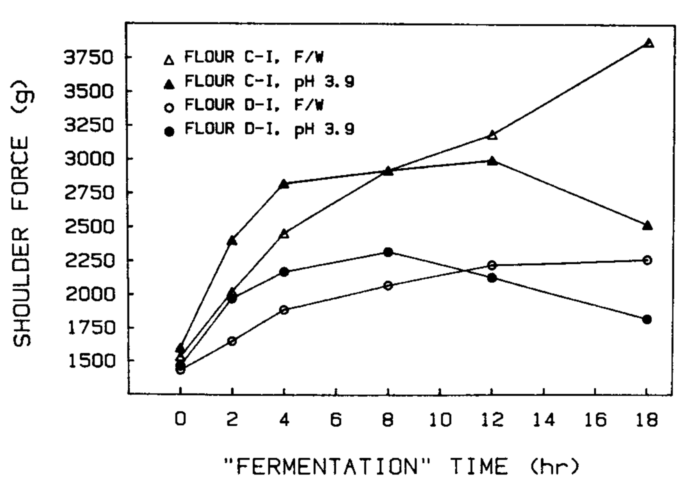

Fig. 7. Shoulder force of cracker doughs as a function of "fermentation" time for flour-water (F/W) sponges and F/W sponges adjusted to pH 3.9 with lactic acid. Standard deviations ($n = 6$) for the measurements at 0, 2, 4, 8, 12, and 18 hr, respectively, are as follows: flour C-I (F/W) = 103, 232, 345, 160, 325, and 281; flour C-I (pH 3.9) = 89, 265, 343, 151, 67, and 181. Flour D-I (F/W) = 196, 217, 264, 82, 319, and 218; flour D-I (pH 3.9) = 52, 288, 52, 166, 258, and 169.

property of the dough that may help explain the differences seen in the finished cracker. A hard wheat cracker dough is very elastic and strong and gives a very thick, dense, undesirable product. The dough also gives higher "apparent dough development" as measured on the KSC. A soft wheat flour dough is usually less elastic, more easily sheeted, and has less shrinkage during baking.

KSC Forces Versus Sponge Formula Variations

Three different doughs made with flour D-I and varied sponge formulations were tested. Sponges from flour and water only; flour, water, and yeast only; and flour, water, yeast, and slurry inoculum (control) were fermented for various times. For each sponge, the mixed dough was given a 4-hr dough time, regardless of sponge fermentation time. Measured peak and shoulder forces are shown in Figures 4 and 5. The peak force of all three doughs decreased with fermentation time, but the flour and water dough decreased the least. The flour, water, and yeast and control sponges showed more rapid decreases in peak force, possibly because of greater hydration that developed at the lower pH. Also, CO_2 aeration would have brought about a decrease in the specific gravity of the dough. Because the same sample volume was used in all testing, this could have the effect of decreasing peak force.

Both flour and water and flour, water, and yeast doughs gave increased shoulder forces with increased fermentation time. Thus, a cohesive, developed dough formed with hydration and fermentation time, increasing "apparent dough development"; however, when the slurry inoculum was added to the sponge, the shoulder force decreased at later fermentation times (after 8 hr). The results of several previous studies of the physical properties of cracker sponges suggested that native flour proteolytic enzymes are involved in bringing about the necessary decrease in strength and elasticity of the sponge (Pizzinatto and Hoseney 1980a, Wu and Hoseney 1989). After 18 hr of fermentation, pH values were 5.15 for flour and water; 4.60 for flour, water, and yeast; and 3.80 for flour, water, yeast, and slurry. It is evident that the slurry inoculum was required to obtain the desired bacterial fermentation and subsequent acid production to achieve a pH of 4.0 or below. Wheat protease is thought to have its maximum activity at pH 3.8–4.1 (Pizzinatto and Hoseney 1980a, Salgo 1981, Wu and Hoseney 1989).

KSC Forces Versus Acidification of Sponges to pH 3.9

If, as assumed, the shoulder force decrease in the previous experiment was caused by an enzymatic effect evident at low pH, similar effects should be seen if the pH were reduced by acid addition. When flour and water sponges of both C-I and D-I flours were set with added lactic acid, the D-I flour (500 g) required 1.75 ml of 85% lactic acid to obtain a sponge pH of 3.9; 1.5 ml was added to the C-I flour sponge. For both acidified sponge doughs, peak force decreased dramatically compared with the flour and water doughs (Fig. 6).

Shoulder forces of the pH 3.9 sponge doughs initially increased more rapidly than those of flour and water doughs (Fig. 7). This is probably because of increased hydration at the lower pH. But for both cases, pH 3.9 sponge doughs gave shoulder forces that eventually decreased.

It was surprising that 8–12 hr at pH 3.8–4.0 was required for the enzymatic activity to decrease the shoulder force, because with the total system the pH would be at that level for a shorter time (Doescher and Hoseney 1985a). It seems probable then that a certain amount of time was required for sufficient hydration before significant effects of enzyme activity could be measured.

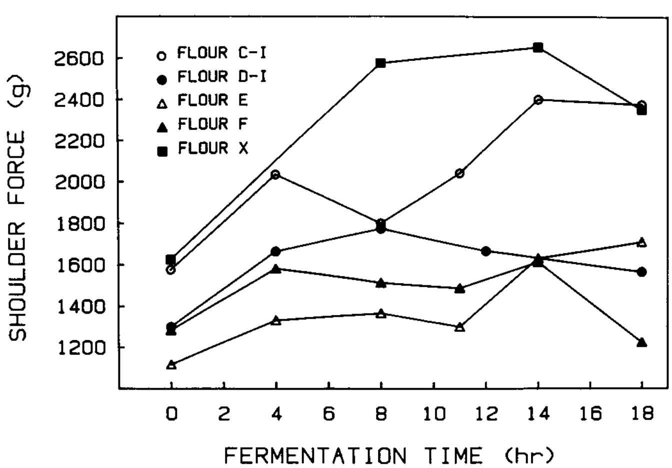

Fig. 8. Shoulder force as a function of fermentation time for a number of flours of known cracker quality. Standard deviations ($n = 6$) for the measurement are as follows: Flour C-I = 129, 216, 0.0, 201, 187, and 209 at 0, 4, 8, 11, 14, and 18 hr, respectively. Flour D-I = 0.0, 175, 164, 248, and 234 at 0, 4, 8, 12, and 18 hr, respectively. Flour E = 153, 153, 82, 127, 82, and 63 at 0, 4, 8, 11, 14, and 18 hr. Flour F = 75, 223, 99, 103, 138, and 170 at 0, 4, 8, 11, 14, and 18 hr. Flour X = 219, 367, 152, and 427 at 0, 8, 14, and 18 hr.

KSC Forces Versus Sponge Fermentation Time

The doughs of four additional flours of various baking qualities, as determined by the laboratory baking test of Rogers and Hoseney (1987), were tested in the KSC at different sponge fermentation times. Finished cracker stack heights and weights are shown in Table II. The objective was to determine if the flours gave differences in their KSC shoulder forces at the varied fermentation times. Peak forces are not shown because the shoulder forces tell the story. The flours tested were soft flours F and E, a soft and hard flour blend C-I, and the hard wheat flour X. Each flour was tested at its optimum cracker absorption (Rogers and Hoseney 1987).

Resulting shoulder forces, along with the previous results for D-I dough for comparison are shown in Figure 8. All doughs gave at least an initial increase in shoulder force values. However, the doughs differed in the changes in shoulder force with longer sponge fermentations. D-I flour, which gave low cracker stack height and weight values (Table II), showed a decrease in shoulder force after 8 hr. Flour E also gave a low stack height and weight (Table II) and showed a decreasing trend in shoulder force at the later stages of fermentation.

Conversely, flour F gave much a larger stack height and weight, and the shoulder force increased with increasing sponge fermentation times. Flour F doughs had the highest value at 18 hr of the three soft flours tested.

These results complement those discussed above. It appears that flours E and D-I may have high proteolytic activities, giving decreased stack measurements and decreased shoulder forces at the longer fermentation times. Flour F, though of poor quality, gave results indicative of a flour with low enzymatic activity, i.e., high stack height and weight and increasing shoulder forces. These results could be related to those of Wu and Hoseney (1989), who found that enzyme extracts from different flours had different abilities to change the rheological properties of a control starch and gluten sponge.

The shoulder force values for X flour dough were high throughout the fermentation times tested. Crackers made from this flour was also high in stack height and weight. Likewise,

TABLE II
Characteristics of Baked Crackers Made with Various Flours

Flour	Stack[a] Weight (g)	SD	Stack[b] Height (mm)	SD
D-I	31.32	2.01	63.01	0.96
E	30.09	2.06	63.27	1.48
F	35.75	2.32	72.02	1.91
C-I	34.15	1.21	69.44	1.35
X	37.95	1.23	78.09	1.67

[a]Stack of 10 crackers, on a dry solids basis.
[b]Stack of 10 crackers.

Wu and Hoseney (1989) reported that a hard wheat flour showed little indication of proteolytic activity at pH 4.0.

Shoulder force results for the C-I flour were higher than expected. Interestingly, the finished cracker characteristics (stack height and weight) were actually intermediate to those of flours D-I and F. It is obvious then that the hard wheat in the C-I blend had a greater effect on the shoulder force values than on the finished product characteristics.

CONCLUSION

Physical properties of cracker doughs were measured using a KSC on an Instron universal testing machine. The peak force taken from the universal testing machine curve appears to measure dough stiffness, and a shoulder force appears to be its function of dough elasticity or dough development.

Flours of differing baked-product quality show different changes or relationships of shoulder force at various sponge fermentation times. Flours that produced crackers with low stack heights had decreased force values at longer fermentation times. Conversely, flours that made poor quality crackers (high stack heights and weights) gave increasing shoulder forces with longer fermentation times. The KSC appears to be useful to characterize the cracker doughs.

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