Dough Profiling: An Instrumental Method for Dough Stickiness Measurement[1]

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ABSTRACT

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Dough profiling, an adaptation of Texture Profile Analysis, was used to measure viscoelastic properties of doughs with varying degrees of stickiness. Results were compared to sensory stickiness scores to determine the applicability of the dough profiling procedure as a stickiness evaluation method. Dough stickiness is a composite characteristic resulting from the balance between adhesive and cohesive forces of a dough. Adhesive and cohesive properties were not assessed separately. Ten flour and water model dough systems, representing an evenly distributed series of stickiness levels from nonsticky to extremely sticky, as determined by sensory methods, were prepared from a standard bread wheat flour using increments of α-amylase or protease enzymes. Profiling was performed on a Lloyd materials testing machine equipped with a size-adjustable profiling cell and using settings determined by response surface optimization. Twenty-four parameters were extracted from the two compression, relaxation, and tension sections of the profiling curve. All of the compression and tension parameters that were read directly from the curves, except stringiness, had coefficients of variation of <10%. Peak compression forces, average compression forces, tension work values for both cycles of the profile, and several relaxation parameter values were highly correlated with sensory stickiness scores ($r \geq 0.95$). The ten doughs could each be clearly distinguished on plots of the first two canonical variables extracted from the full set of profile parameters. Dough profiling is a promising technique for evaluation of dough stickiness.

The 1BL/1RS chromosomal translocation has been widely incorporated into wheat cultivars to provide rye genes that increase disease resistance, produce higher grain yield, and improve agronomic performance (Henry et al 1989, Dhaliwal et al 1990). The translocation can also influence flour properties and have strongly negative effects on dough handling and breadmaking quality. Problems that have been reported include excessive dough stickiness, low dough mixing tolerance, and reduced bread volume (MacRitchie et al 1986, Martin and Stewart 1986, Dhaliwal et al 1990, Barnes 1990, Graybosch et al 1993). The dough stickiness problem is of particular concern to large mechanized bakeries where it can result in costly disruptions to production schedules and in loss of product quality. Wheat breeding programs and the baking industry need a reliable, rapid, quantitative, instrumental method for measuring stickiness.

Stickiness evaluation is influenced by the forces of adhesion and cohesion (Sherman 1979). According to Saunders et al (1992), the properties of doughs that result in stickiness during processing are similar to the properties of pressure-sensitive adhesives that result in pressure-sensitive tack, and include both rheological and surface phenomena. In the same way that pressure-sensitive adhesives are viscoelastic elastomer-resin systems, doughs are viscoelastic glutenin-gliadin systems (Levine and Slade 1990). Heddleson et al (1993, 1994) concluded, from dynamic rheological studies and probe tack tests of flour and water systems, that viscoelastic behavior determines the extent of pressure-sensitive tack, or stickiness, of wheat flour doughs, and that the critical factor is the ratio of adhesive to cohesive forces.

A number of reports have described instrumental tests for stickiness, but the methods have suffered from poor reproducibility or have lacked standardization against quantitative measurements. Martin and Stewart (1986), using an Ottawa Texture Measuring System, compressed dough onto a plate with a plunger and measured the force required to raise the plunger with dough adhering to both plunger and plate. They reported that the results of this testing method were not satisfactory. Atkins (1989), using an Instron Universal Testing Machine, compressed a 10-g ball of dough between steel plates and then raised the upper plate until the dough pulled away. Force and time were measured throughout this cycle. He reported that results lacked sufficient precision to allow prediction of stickiness of individual doughs, although compression energy values were highly correlated with stickiness scores for the data as a whole. Dhaliwal et al (1990) used a Digital Gram Gauge to measure compression and tensile forces when the probe of the gauge was first pressed against dough adhering to a perforated plate, then pulled away from the dough surface. The height of the tensile force peak multiplied by the width of the peak was used as a measure of stickiness. Values calculated in this way gave reproducible differences between 1B/1R hard wheats and their recurrent parents, but the authors stated that there was no certainty that these values could be used to distinguish among lines differing in degree of stickiness, and values were not compared to a noninstrumental standard.

Chen (1992) assessed stickiness using the Texture Technologies Corporation TA.XT2 texture analyzer, equipped with a fixture designed to extrude a thin layer of dough through a fine screen. The measure of stickiness used was the force required to withdraw a plunger from the extruded surface after a short compression period. The method was evaluated by testing doughs which had been subjectively classified as very sticky, sticky, or nonsticky. Instrumental force values were highest for the very sticky doughs and lowest for the nonsticky doughs, but values for doughs within each category ranged widely, and there were relatively small differences in values of some doughs classified as belonging to different stickiness categories.

This article describes the development of a standardized, reproducible procedure for dough stickiness measurement. The method, which we call dough profiling, uses an adaptation of the traditional Texture Profile Analysis (TPA) described by Friedman et al (1963) and Szczesniak et al (1963) and modified by Henry and Katz (1969) and Bourne (1978), to measure viscoelastic characteristics of dough. While the profiling technique is not new, the design of the measuring cell, the introduction of a relaxation phase, the mathematical data analysis for the two compression-

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relaxation-tension cycles, and the application to dough properties are novel.

The principal objective of this study was to evaluate the potential of the dough profiling method to provide a sensitive and reproducible instrumental test for stickiness, a test with values well correlated to sensory stickiness scores as determined by the method of Wang et al (1994).

MATERIALS AND METHODS

Experimental Design

This article includes the results of two experiments. The first was designed to compare instrumental test settings for dough profiling to determine the best combination for discriminating among nonsticky, moderately sticky, and very sticky doughs. The second was designed to evaluate reproducibility of the measurements derived from the dough profiling curve and to identify parameters that alone or combined could be used to measure stickiness.

Experiment I. Three types of dough: nonsticky, moderately sticky, and very sticky, were profiled instrumentally using a series of crosshead speed, degree of compression, and sample size combinations. A central composite rotatable design for three variables at five levels, with four trials at the center point, was used to reduce to 18 the number of trials necessary to identify the best combination for each type of dough (Haaland 1989). Table I lists the actual values and the coded values of the independent variables. Eighteen parameters were measured and included in the data analysis.

Experiment II. Ten doughs with a wide range of stickiness were prepared and profiled using the instrumental settings determined in Experiment I. Each type of dough was profiled three times, and the 30 profiling tests were run in a randomized order. Twenty-four parameters were extracted from the profiling curves for data analysis.

Materials

Straight-grade flour, milled from Columbus Hard Red Spring bread wheat on a Buhler Laboratory Mill, was supplied by the Agriculture and Agri-Food Canada Winnipeg Research Centre. The flour had 13.7% moisture, 14.6% protein, and 0.52% ash (AACC 1991). Farinograph absorption, based on a 50-g bowl and constant flour weight (AACC 1991), was 62.2%. α-Amylase: Ref. A2771 (activity: 2 SKB units/g), and protease: Ref. P4032 (activity: 4 SKB units/mg) were obtained from Sigma Chemical Co., St. Louis, MO.

Texture Testing Equipment

Dough profiles were determined using a Lloyd Materials Testing Machine (LMTM) model 1000R, with Rcontrol software. A dough profiling test cell, designed and constructed in our laboratory, was mounted on the LMTM (Fig. 1). The cell was composed of four main parts: a solid plexiglass upper plate, a perforated plexiglass lower plate, a slotted plexiglass spacing ring, and an aluminum stand. Cylindrical perforations in the lower plate ensured good dough-to-plate adhesion and reduced bubble formation between the dough and the plate surface. The upper and lower plates had grooves in the edges of the plates. The grooves were aligned to slots in the spacing ring so that the plates could be held in place with thin metal bars. This arrangement allowed sample heights to be varied from 1.6 to 29.6 mm in steps of ≈1.6 mm. The profiling cell was designed to prevent exposure of dough surfaces to air, to ensure that the contact area remained the same from sample to sample, and to keep sample heights consistent.

TABLE I
Levels of Independent Variables Corresponding to Coded Values

	Code Level				
Independent Variables	**–1.682**	**–1**	**0**	**+1**	**+1.682**
Compression rate (mm/min)	10.0	28.4	55.0	81.7	100.0
Compression level (%)	10.0	18.1	30.0	41.9	50.0
Sample height (mm)	7.2	10.1	14.3	18.5	21.4
Corresponding wt (g)[a]	14.0	20.0	28.0	35.0	41.0
	(25)	(35)	(50)	(65)	(75)

[a] Sample weights corresponding to each height used in the design (percent of the total mixed dough).

Dough Preparation and Handling

Doughs made with 35 g of flour (14% mb), distilled water, and enzyme were mixed on a 35-g mixograph set at 90 rpm. Room and ingredient temperature were held at 21 ± 1°C. Water was calculated based on farinograph water absorption by the formula: water (g) = 35 (farinograph water absorption –3%). Enzymes were obtained in powdered form, stored at 4°C, and dissolved in formula water at room temperature just before the doughs were mixed. In Experiment I, doughs that were nonsticky, moderately sticky, and very sticky (sensory stickiness scores of 12, 23, and 28

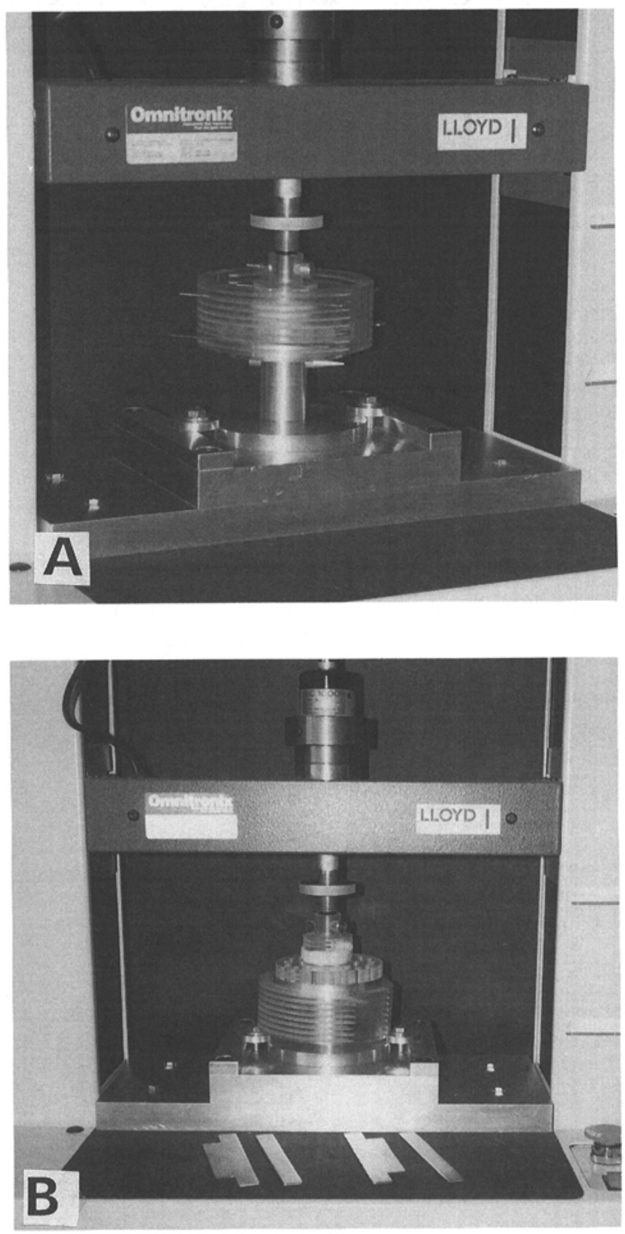

Fig. 1. Lloyd Materials Testing Machine (LMTM) model 1000R, with dough profiling cell in position, ring not removed **(A).** LMTM, profiling cell and dough at the beginning of the two-cycle dough profiling test **(B).**

respectively, as determined by the method of Wang et al 1994), were produced by adding nothing to the first dough, 1 g of α-amylase to the second dough, and 6.125 mg of protease to the third dough. Following the method of Wang et al (1994), these doughs were mixed to 1.2 times the Mixograph Dough Development Time (MDDT) of the flour. Mixing times were not altered for added enzymes. In Experiment II, the amounts of amylase and protease were adjusted to produce 10 increasingly sticky doughs, as shown in Table II. These doughs were mixed for 170 sec, the MDDT of the flour.

A standardized procedure for dough sampling and handling was followed to maximize reproducibility. First, the wide slotted ring was positioned around the upper plate of the profiling cell, which was inverted, placed on a balance, and tared. A sample of freshly mixed dough was then transferred from the mixer bowl onto the plate. The weight of sample was controlled for each height setting used, and represented a fixed percent of the total mixed dough weight (Fig. 2A). After a 5-sec resting period, the dough was covered by the inverted lower plate (Fig. 2B). The position of this plate was secured by metal bars inserted through the slotted ring into grooves on the edge of the plate. The fully assembled test cell and dough was mounted on the LMTM by first flipping the cell over so that the stem of the lower plate could be pinned to the aluminum stand (Fig. 2C), then securing the stand to the base of the LMTM, and finally positioning the crosshead so that it could be attached to the upper plate (Fig. 2D). Just before beginning the profiling run, the slotted ring was lowered to the base of the instrument.

Dough Profiling

Doughs were profiled on the LMTM using the profiling cell to hold the doughs, and a 10-kg maximum force load cell to measure compression and tension forces. Doughs were subjected to two compression-relaxation-tension cycles. Movement of the crosshead was programmed for varying compression-tension rates and limits by using the Lloyd Rcontrol software. Times for compression and tension were not set, but were determined by crosshead rate and percent compression settings. Relaxation times for both cycles were set at 45 sec for all profiling runs. Force during testing was recorded every 0.1 sec, and these data used to measure the primary parameters.

A typical dough profiling curve is shown in Figure 3. Dough profiling parameters extracted from the curve are listed in Table III. The primary compression parameters CF1, CF2, CW1, and CW2, and tension parameters TF1, TF2, TW1, and TW2, as well as the stringiness values S1 and S2, were measured directly from the curve. Compression peak force values, CF1 and CF2, were the maximum forces recorded during the first and second compression cycles respectively. Compression work values were measured as the areas under the compression curves over the period of the first compression stroke (CW1) and over the period of the second stroke (CW2). Tension peak force values, TF1 and TF2, were the maximum forces recorded during the tension strokes of the cycle one and cycle two, respectively, and tension work values, TW1 and TW2, were calculated from the areas of the negative curves plotted during the tension phase of both cycles. Stringiness was measured as the distance from the onset of tension to the sample break for the first cycle (S1) and the second cycle (S2). Average compression forces, AC1 and AC2, were calculated by dividing the compression work value by the time in seconds from the start to the end of the compression peak, for each cycle. Average tension force values were calculated by dividing the tension work by the stringiness values, for each cycle. Approximately half of the parameters listed conform to standard definitions used for TPA (Bourne 1978). The other half have been newly defined for dough profiling: average compression force of cycle 1 and cycle 2 (AC1 and AC2), average tensile force of cycle 1 and cycle 2 (AT1 and AT2), two combinations of tension parameters (CT and GT), and six parameters extracted from the relaxation portions of the curve (R1, R2, K1, K2, M1, and M2). During the relaxation portion of

TABLE II
Enzyme Levels and Sensory Stickiness Scores for Experiment II

Sample	α-Amylase (g)	Protease (mg)	Sensory Stickiness Score[a]
1	···	···	8.0
2	0.25	···	11.5
3	0.75	···	16.0
4	1.00	···	18.0
5	1.25	···	21.0
6	···	6.0	25.0
7	···	7.5	32.0
8	···	9.0	35.0
9	···	10.5	39.0
10	···	12.0	43.0

[a] 0 = nonsticky and 45 = extremely sticky.

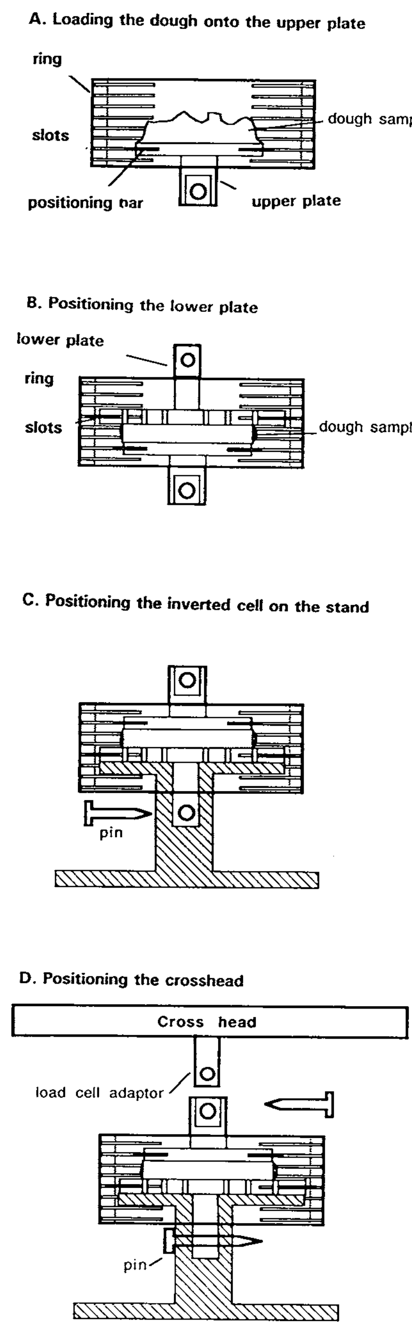

Fig. 2. Preparing the dough sample for testing: (**A**) loading the dough onto the upper plate, (**B**) placing the lower plate in position, (**C**) inverting the profiling cell onto the stand, (**D**) positioning the crosshead.

the curve, from the end of the compression phase to the beginning of the tension phase, the crosshead was held stationary. Forces recorded during this part of the test were analyzed to determine relaxation parameters based on the formula:

$$R = 1 - F(t_{45})/F(t_0) \quad (1)$$

where R is the relaxation degree, $F(t_{45})$ is the compression force registered at the end of the relaxation period, and $F(t_0)$ is the compression force at the beginning of the relaxation period (the peak compression force); and:

$$F(t)/F(t_0) = M\, t^K \quad (2)$$

where $F(t)$ represents compression force readings from 0.5–45 sec, M is the ratio of the relaxation force at 1 sec (as calculated by regression analysis) to the compression peak force, and K is the relaxation index. Both M and K are related to the dough relaxation rate, or relaxation force decay rate, which is a characteristic of dough viscoelasticity. The relationship between relaxation force and time is logarithmic, except during the initial 0.5 sec of the relaxation part of the cycle. Relaxation index K tends to 0 (or M tends to 1) with greater dough strength, that is, when the dough is more elastic than viscous. Conversely, K tends to 1 and M to 0 when dough is weak, and viscosity predominates over elasticity.

Sensory Scoring

Doughs were scored on 15-cm long, anchored, continuous line scales for: 1) ease of dough removal from mixograph bowl and pins, 2) stickiness to fingers, and 3) manual moldability as described by Wang et al (1994). Using this method, the maximum possible score for stickiness is 45 and possible dough scores range from 0 to 45 (0 = no stickiness, 45 = extremely sticky).

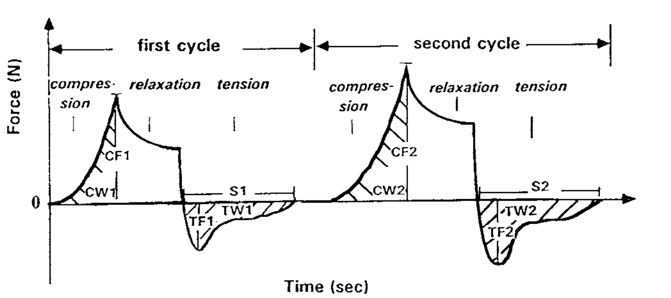

Fig. 3. Dough profiling curve of a commercial bread flour, showing two compression, relaxation, and tension cycles.

TABLE III
Dough Profile Parameter Definitions[a]

CF1 and CF2	Compression peak force ((N)
TF1 and TF2	Tension peak force (N)
CW1 and CW2	Compression work (mJ)
TW1 and TW2	Tension work (mJ)
S1 and S2	Stringiness (mm) – distance between the onset of tension and sample break
AC1 and AC2	Average compression force (N)
AT1 and AT2	Average tension force (N)
R1 and R2	Relaxation degree (1 – compression force at end of relaxation ÷ compression force at beginning of relaxation)
K1 and K2	Relaxation index (from relaxation model: $F(t)/F_0 = M\, t^K$)
M1 and M2	Relaxation ratio' (from relaxation model: $F(t)/F_0 = M\, t^K$)
CC	Cohesiveness (CC = CW2/CW1)
GC	Compression force × work ratio (gumminess) (N) (GC = CF1[CW2/CW1])
CT	Tension work ratio [CT=TW2/TW1]
GT	Tension force × work ratio (N) (GT = TF1 [TW2/TW1])

[a] 1 = first cycle, 2 = second cycle.

Statistical Analysis

SAS procedures ANOVA, GLM, G3D, and GCONTOUR (SAS 1989) were used to determine response surface regression equations and diagrams for Experiment I. The response surface diagrams for the three doughs were compared visually for each of the profiling parameters. To determine the best settings for discrimination among doughs, two additional response surfaces were plotted: a surface, D2,

representing the difference between the moderately sticky (MS) and very sticky (VS) doughs (D2 = MS – VS), and a surface, D1, representing the difference between nonsticky (NS) and sticky doughs (D1 = NS – [MS + VS]/2). Contour plots of D1 and D2 were overlaid to identify the settings at which differences were maximized for both plots.

Coefficients of variation (CV) for each texture profile parameter were calculated using the center point data of Experiment I, and also using the replicated data of Experiment II. Mean CV for each parameter, determined by averaging the CV obtained for individual doughs, was used to evaluate reproducibility of the parameter.

A SAS discriminant procedure, CANDISC, was used to analyze the data of Experiment II. CANDISC is a dimension reduction technique that combines elements of principal component analysis and canonical correlation. The procedure computes canonical variables, linear combinations of the original quantitative variables, that summarize between-class variation. In the analysis of the experimental data from Experiment II, the original texture profile values were used to calculate canonical variables CAN1, CAN2, etc., which best summarized between-dough variation. A plot of CAN1 versus CAN2 was generated to determine the degree to which the original data discriminated among the 10 doughs.

RESULTS

Determination of Instrumental Settings

In the first experiment, the effects of instrumental settings on texture profile values were examined using three doughs with marked differences in stickiness. Response surface diagrams were generated for the texture profile parameters by plotting compression rate versus compression percent for samples of three sizes (heights of 7.2, 14.3, and 21.4 mm). Parameter values for all three doughs were strongly influenced by sample size and percent compression. To determine the best settings to use for discriminating among the doughs, diagrams (D1), showing the degree of differ-

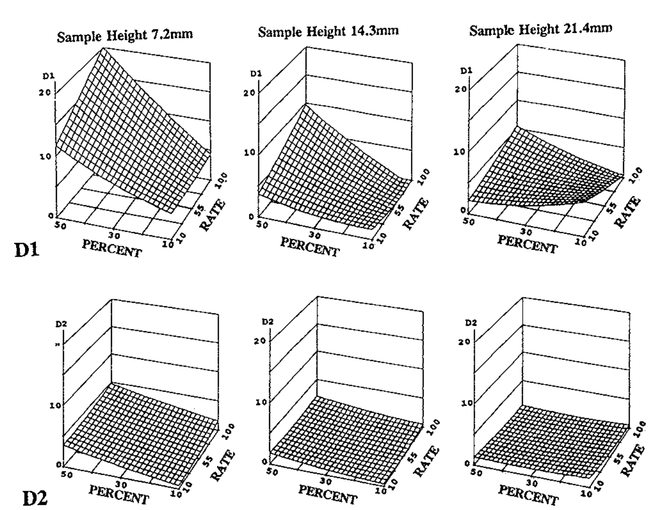

Fig. 4. Response surface diagrams showing the effect of compression percent and crosshead descent rate on values of samples D1 and D2 at three sample heights for the compression parameter CF1.

ence between nonsticky and sticky doughs (averaged values for the moderately and very sticky samples), and diagrams (D2), showing the degree of difference between moderately and very sticky doughs, were plotted. For CF1, response surface plots of D1 and D2 (Fig. 4), showed that differences were greater with the highest compression level (50 %), the fastest compression rate (100 mm/min), and the smallest sample size (height 7.2 mm) than with other settings. When response surface diagrams and contour plots for D1 and D2 of all the main texture profile parameters were plotted and compared, the best discrimination was obtained with these settings for most of the primary parameters, plus AT, AC, and GC. These settings were not, however, optimum for all of the parameters. The tension work parameters TW1 and CT gave greater differences with sample heights of 14.3 and 21.4 mm, respectively, and two parameters, CC and GT, had highest D1 and D2 values at the lowest compression level, slowest compression speed, and greatest sample height. It was concluded that the 7.2-mm sample height, 50% compression, and 100 mm/min compression rate combination, which gave effective discrimination for all 24 parameters, even those for which these conditions were not the optimum, was the best to use for general texture profiling.

In Experiment I, the only trials repeated were for the combination of settings that represented the response surface design center point. As an initial indication of the reproducibility of the data, CV were calculated for these data. Average CV for first cycle parameters were 5% for R1 and S1, 8% for TF1, CW1, TW1, AC1, and AT1, and 9% for CF1. When calculated for the doughs individually, first cycle CV were all <12%, even those for the very sticky dough. Average CV for second cycle parameters were generally higher, but for R2, TF2, and AT2, were still <10%, and for the remaining parameters were <20%. The manipulation that occurs during the first cycle was probably responsible for the higher CV of second cycle parameters.

Comparison of Compression, Tension, and Relaxation Values for 10 Doughs with Varying Degrees of Stickiness

For the 10 doughs studied in Experiment II, CF1 values were highest for the nonsticky, control flour dough (55 N). CF1 values were lower for the slightly to moderately sticky doughs (30–40 N) and much lower for the sticky and very sticky doughs (20–30 N) (Fig. 5). CF2 values were higher than CF1 values for all of the doughs, probably reflecting the effects of first-cycle manipulation. In a similar way, values for CW and AC were higher for nonsticky than for sticky doughs, and values for the second cycle were higher than for the first. Tension peak force values were high (>32 N) for the least sticky doughs, lower (26–28 N) for the four slightly to moderately sticky doughs, and lower still (22–25 N) for the sticky and very sticky doughs (Fig. 6). This pattern was repeated for the TW and AT parameters. The relationship of tension-based measurements to stickiness appeared less consistent than the relationship of compression-based measurements.

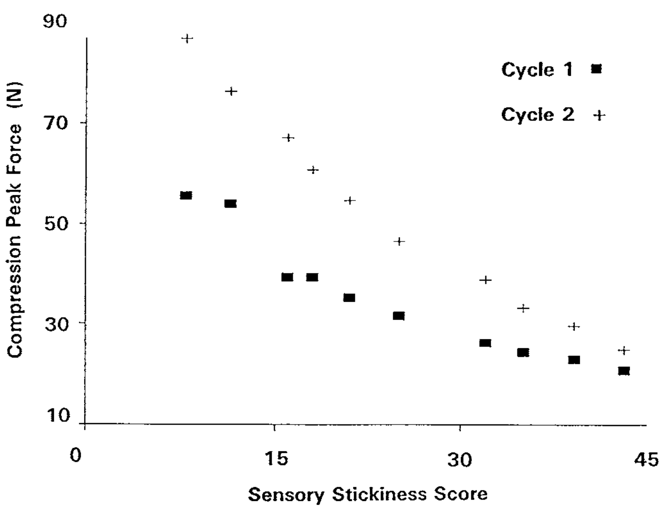

Fig. 5. Plot of compression peak force values vs. stickiness scores, Experiment II.

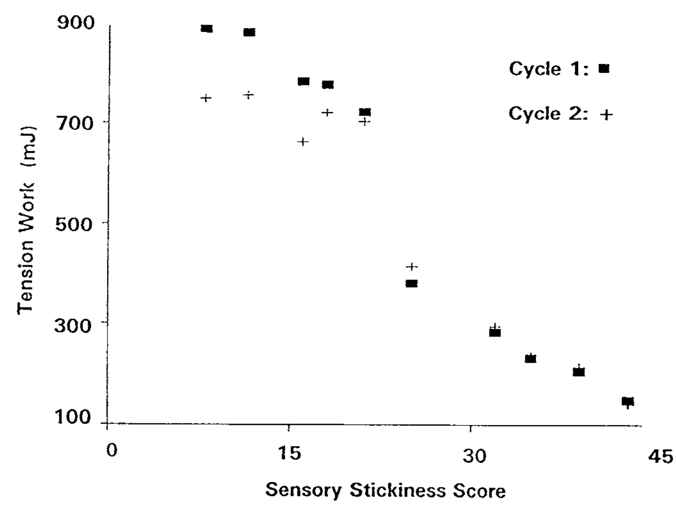

Fig. 7. Plot of tension work values vs. stickiness scores, Experiment II.

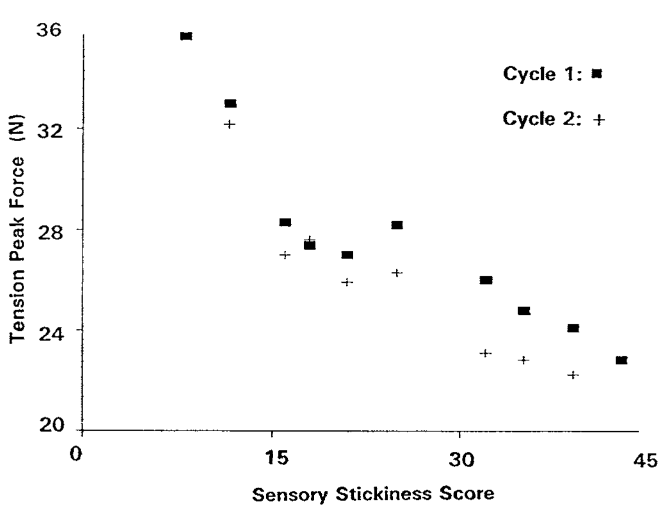

Fig. 6. Plot of tension peak force values vs. stickiness scores, Experiment II.

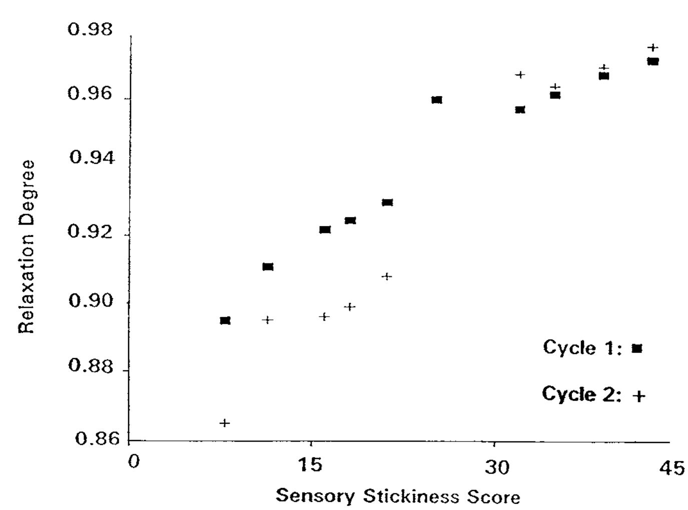

Fig. 8. Plot of relaxation degree values vs. stickiness scores, Experiment II.

Values for TW (the areas below the baseline on the profiling curve) were high for the control and four less sticky samples, and low for the remaining five sticky to very sticky samples (Fig. 7). Tension work values for dough 6 were half those for dough 5, although stickiness scores as determined by the sensory method were only a few points higher. Doughs 6–10 were treated with protease, which probably caused a reduction in gluten strength and elasticity that was reflected more in the tension work values than in the stickiness scores.

Relaxation degree (R1 and R2) values increased linearly as dough stickiness scores increased, except for one dough. Dough 6 had greater R1 and R2 values than expected, based on degree of stickiness (Fig. 8). This anomalous value corresponds to the dough with the lowest level of protease, and again may reflect changes in the protein that did not initially influence the sensory scoring for stickiness.

In Experiment II, using the optimized settings for compression level, crosshead speed, and sample size, the CV were <10% for all of the primary parameters, except S1 and S2, which had CV of ≈15%. The calculated parameters that used stringiness, AT1 and AT2, had CV of 13 and 18%, respectively. All of the relaxation parameter values for both cycles had CV of <10%, except M2 (13.8%). High CV for stringiness values were attributed to the difficulty of determining the end points of the tension curves for sticky doughs.

Twelve of the dough profile parameters were highly correlated with sensory scores ($r \geq 0.95$). Nine of these parameters: CF1, CF2, GC, AC1, AC2, CW2, R1, M1, and M2, had CV of ≤10%, and appeared promising for measurement of stickiness. Two of the 10 parameters, M2 and AT2, were less precise, as indicated by higher CV, and one, TW1, did not give consistent results for the two types of enzyme modification used to produce stickiness.

Canonical Analysis

A canonical analysis of the replicated profile data for the 10 doughs was made to determine whether the complex of dependent variables obtained by dough profiling could discriminate effectively among the doughs. The first and second canonical variables, CAN1 and CAN2, determined by canonical analysis, explained most of the variation between the doughs. The cumulative R^2, after inclusion of the two variables in the model, was 0.9752. Dough means on the first two canonical variables showed wide differences among the 10 samples, and the canonical plot of CAN1 and CAN2 showed distinct nonoverlapping groupings for each of the 10 doughs (Fig. 9). The canonical analysis therefore confirmed the power of dough profiling to discriminate between doughs with even relatively small differences in stickiness over the entire stickiness range.

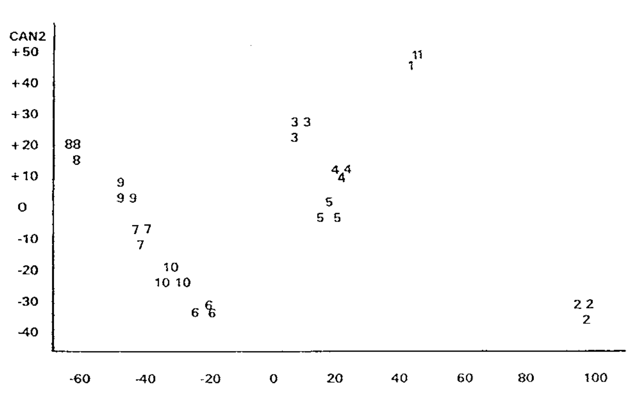

Fig. 9. Plot of the first two canonical variables, Experiment II.

DISCUSSION

In the previous sections of this article, we have used the term "stickiness" to refer to the complex of properties, present in some wheat flour doughs, that cause doughs to adhere to hands or equipment during the breadmaking process. Dough stickiness is a form of pressure-sensitive adhesion and is a consequence of both surface energy and cohesive strength of the dough (Heddleson et al 1993). In a pressure-sensitive adhesive (PSA), high molecular weight rubbery polymers give elasticity, and low molecular weight resins contribute viscosity, and the two combine to produce effective adhesion (Heddleson et al 1994). The property responsible for the behavior of a PSA is pressure-sensitive tack, which enables bonding to occur as soon as the PSA makes contact with another surface. The strength of the bond depends on both the surface chemistry and the rheological properties of the PSA (Saunders et al 1992). In the case of adherence between a high-energy surface, such as a metal probe, and a low-energy surface, such as that provided by dough, adhesive performance (pressure-sensitive tack) will be largely determined by the viscoelastic properties of the PSA (Heddleson et al 1994).

Viscoelastic properties of a wheat flour dough originate with gluten and are strongly influenced by dough moisture content, mixing method, and temperature, as well as by the balance of components within the gluten itself (Janssen at al 1990, Heddleson et al 1994). Low molecular weight gliadins provide the main viscous components in the system, while high molecular weight glutenins contribute elasticity (Levine and Slade 1990). Interactions between glutenins and gliadins, and between these components and water, under different mixing and testing conditions, will determine tack behavior and the degree of stickiness of a dough. It has been shown that when the internal cohesive forces of a PSA are sufficiently high, measured as the storage modulus (G') by dynamic rheological testing, tack does not occur (Heddleson et al 1993). The problems associated with processing of sticky doughs are therefore as much the result of internal cohesive failure as of high surface adhesiveness, and methods for measuring dough stickiness should evaluate cohesive as well as adhesive forces.

Dough profiling, as described in this article, is an empirical testing method that makes it possible to compare the effects of differences in dough viscoelastic properties, by measuring the force required to compress or stretch dough, and the force exerted by compressed dough during relaxation. In Experiment II, the values for many of the profiling parameters were highly correlated with stickiness scores. Parameters calculated from compression and relaxation force measurements were usually better indicators of stickiness than were parameters based on tension force measurements. This result was unexpected because the tension work area of the profiling curve has traditionally been interpreted as a measure of adhesiveness (Szczesniak 1963, Bourne 1978), and the contribution of cohesiveness to tension work values has not been considered.

The discriminating power of profiling parameters as a group was evident in the canonical correlation analysis performed using the data for Experiment II. The capacity for discrimination of the combined data suggest that a reduced set of compression, tensile and relaxation parameters might be combined mathematically to provide a composite indicator for stickiness.

CONCLUSIONS

Dough profiling is a promising method for dough stickiness measurement. A number of the parameters measured from the profiling curve were highly correlated with sensory values for stickiness and had good reproducibility. Canonical analysis indicated that doughs with small variations in stickiness could be discriminated from each other using weighted combinations of variable values. Further dough profiling studies should be conducted with flours naturally differing in dough stickiness to determine the best combination of parameters for dough stickiness measurement. This work is now being done using a set of 1BL/1RS translocation lines and a set of corresponding near isogenic wheat controls.

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