Dough Microextensibility Method Using a 2-g Mixograph and a Texture Analyzer

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ABSTRACT

Development of a small-scale method to measure dough extensibility, using a 2-g mixograph and the TA.XT2 texture analyzer (TA) equipped with Kieffer rig, suitable for early-generation wheat quality screening is presented. Three hook speeds 3.3, 7.0, and 10.0 mm/sec were tested on the TA. Only at the lower hook speed of 3.3 mm/sec were wheats, varying in quality, clearly differentiated. The ability to differentiate between wheats using the TA was compared with the Brabender Extensigraph. The sample ranking based on the resistance to extension (R_{max}) from the TA at a hook speed of 10.0 mm/sec correlated highly (r = 0.99) to the ranking obtained on the extensigraph. Dough extensibility data from the extensigraph and the TA, using hook speed 10.0 mm/sec, was correlated (r = 0.90) to loaf volume. Similarly, dough extensibility on the TA, using hook speed 3.3 mm/sec, was correlated to loaf volume (r = 0.96). The effect of three dough water contents (farinograph absorption, farinograph absorption + 6%, and 2-g mixograph water absorption) on physical properties of dough were evaluated by mixing the dough in a 2-g mixograph and testing the extensibility on the TA. Dough prepared at farinograph absorption + 6% and at mixograph absorption allowed differentiation between wheats based on the resistance to extension (R_{max}).

In a breeding program, the success of the early-generation wheat quality screening relies on small-scale methods because of the limited sample size. Dough rheology is a very important component of wheat quality screening in predicting the physical properties of the dough as well as the quality of the end product. Dough extension properties are of special interest to the baker because they influence dough properties during dough development, fermentation and oven spring (Bloksma 1990). The extensigraph was introduced in 1936 by C. W. Brabender to simulate the fermentation process and oven spring in conventional breadmaking even though deformation (strain) rate of dough using an extensigraph is several hundredfold higher when compared with the strain rate level typically observed during dough fermentation and oven spring (Bushuk 1985, Bloksma 1990). The advantage of the uniaxial extensibility method is the ability to monitor changes in the dough properties resulting from changes in process and ingredients among wheats with different dough strength (Weipert 1991). Despite the complexity of the baking test and difficulty in predicting loaf volume (LV) by any single rheological parameter (Janssen et al 1996), numerous reports suggest a positive relationship between simple extension parameters observed on the extensigraph and LV (Irvine and McMullan 1960, Bolling and Weipert 1984, Campbell et al 1987, Cressey et al 1987).

The extensigraph offers an empirical measurement of stress-strain relationship in a dough after defined rest periods and dough geometry (Preston and Hoseney 1991). The extensigraph parameters commonly used to characterize dough extension properties are the maximum resistance (maximum height of the curve) in extensigraph units (R_{max}), the extensibility from start until dough rupture (E), the area under the curve in square centimeters (A), and the viscoelastic ratio determined by the ratio of maximum resistance to extension (R_{max}/E). The standard extensigraph method (Approved Method 54-10, AACC 1995) requiring a 300-g sample is not practical for early-generation breeding programs. Increasing interest in dough microtesting methods has stimulated the development of alternative instruments and methods (Tschoegl 1970a; Evans et al 1974; Rasper 1975; Schlichting et al 1996; Kieffer et al 1981, 1998).

Of particular interest has been the introduction of the TA.XT2 texture analyzer (TA) (Texture Technologies Corp., Scarsdale, NY/ Stable Microsystems, SMS, Godalming, Surrey, UK) equipped with SMS/Kieffer dough and gluten extensibility rig to perform a simple extension test on small (≈0.8 g) dough strips (Hou et al 1996, Kieffer et al 1998). The TA does not control the dough deformation rate, although it offers variable hook speed control. Increasing the hook speed has resulted in increased dough stress (Prihoda and Bushuk 1971, Ingelin and Lukow 1997). Dough treatment history, which includes mixing, molding, and resting conditions, is as important a factor as the type of extension instrument itself (Tschoegl et al 1970b, Weipert 1991). In addition, water level in the dough influences the rheological properties including tensile strength (Muller and Hlynka 1964), and the test results are therefore meaningful only at a specified water level. Some researchers have suggested constant water absorptions (Muller and Hlynka 1964), whereas others prefer mixograph-optimized water levels (Ingelin and Lukow 1999).

The present study was designed to 1) compare the traditional dough extension method using an extensigraph with the microextension method using a TA, and 2) compare different hook speeds and dough water levels on a TA to determine the parameters that would best differentiate the quality characteristics of wheat flour samples.

MATERIALS AND METHODS

Two sets of wheat samples were used in this study. Sample Set 1 including nine spring wheat cultivars and one experimental line, with identical high molecular weight (HMW) glutenin subunit composition (2*, 7+8, 5+10) but varying widely in baking quality was grown in 1995 in one western Canadian location. This sample set consisted of three Canada Western Red Spring (CWRS), two U.S. Hard Red Spring (HRS), one Australian Prime Hard (APH), one Canada Prairie Spring (CPS) advanced experimental line, and three Canada Western Extra Strong Red Spring (CWES) wheat cultivars. Sample Set 2 consisted of 24 advanced experimental hard red spring lines and five CWRS check cultivars grown in 1996 in western Canada with flour protein contents of 12.3–17.6%, 14% mb. Both sets of wheats were milled into straight-grade flour using a Buhler experimental mill. Farinograph water absorptions (FAB) were determined using the standard method (Approved Method 54-21, AACC 1995). A 2-g micromixograph (National Mfg. Div. TMCO, Lincoln, NE) optimized flour absorption (MAB) according to the method of Ingelin and Lukow (1999). Flour protein content (N × 5.7) was determined by micro-Kjedahl procedure (Approved Method 46-13, AACC 1995).

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Comparison of Extensigraph and TA

The extension parameters from the extensigraph and TA obtained from Sample Set 1 flours were compared. The dough was prepared from 50 g of flour (14% mb) and 2% salt; it was mixed for 1 min, rested for 5 min, and then mixed to peak consistency (500 BU) in a 50-g farinograph bowl according to the extensigraph method (Approved Method 54-10, AACC 1995). Out of the resulting 80–85 g of dough, a 75-g dough piece was used for the small-scale extensigraph test (Oliver 1979, Bebyakin and Ishina 1981). This method enabled the recording of all of the extension parameters from each of the samples, including the CWES wheats (Glenlea) that were too strong to record R_{max} on the chart, a problem also reported by Ingelin and Lukow (1997). For the extension test using a TA, the remaining portion of the dough was divided into three pieces (≈2.5 g each) placed into a Teflon-coated block to prepare dough strips according to the method of Kieffer et al (1981 and 1998), and rested for 45 min at 30°C, 95% rh. The dough strips were equilibrated to 25°C and tested on a TA at three different hook extension speeds: 3.3, 7.0, and 10.0 mm/sec, representing a TA working hook speed range (0–10 mm/sec). The 3.3 mm/sec hook speed is recommended by the manufacturer for dough and gluten extension tests, whereas the extensigraph hook speed is fixed at 14.5 mm/sec. The parameters recorded were area under the curve (*A*), extensibility until dough rupture (*E*), R_{max}, and R_{max}/E.

Microscale Extension Test Using a 2-g Mixograph and TA

The 2-g mixograph and TA were used to evaluate a small-scale extension test using Sample Set 2 at three water absorption levels: FAB, FAB+6%, and 2-g mixograph MAB. On an initial mixograph run, 2 g of flour (14%mb) and 2% salt (w/w) were mixed to determine peak development at three different absorptions. The second mixograph was run under the same conditions, but mixing was interrupted at peak development. The dough was rounded gently into a ball and placed over three to four channels of the Teflon-coated block (Kieffer et al 1981) that had been prepared by placing thin nonadhesive Teflon strips (2 × 60 mm) coated in mineral oil in the channels. The upper half of the block was placed in position and tightly clamped, which distributed the dough over three to four channels to yield an equivalent number of dough strips of uniform geometry. The dough was rested for 45 min at 30°C and 95%rh. Before the test, the dough (still in the press) was equilibrated for 10 min to 25°C. The individual dough strips were then separated from the Teflon strips, positioned across the Kieffer rig dough holder, and immediately tested on a TA at the hook speed of 3.3 mm/sec and a trigger force of 1 g. Primary parameters recorded were *A*, *E*, and R_{max}.

Baking Test

The optimized long-fermentation bake test (Approved Method 10-10B, AACC 1995) at water level of FAB — 2% was used to evaluate the baking potential of the flours from both sample sets. The method was based on 100 g of flour (14% mb) and contained sugar (6 g), instant yeast (1 g), shortening (3 g), whey powder (4 g), and 20 ppm of L-ascorbic acid. Doughs were mixed in a GRL-200 mixer (Kilborn and Tipples, 1974) to peak development at 140 rpm. LV was measured by rapeseed displacement.

Statistical Evaluation

All analyses were performed in triplicate unless specified otherwise. The reproducibility of the data was checked using residual

TABLE I
Overall Quality of Sample Set 1

Wheat[a]	Flour Protein[b] (%)	FAB[c] (%)	DDT[d] (min)	LV[e] (cm^3)	Mixing Time[f] (min)
Alpha16 CPS	8.6	55.0	1.5	600	5.5
Era HRS	11.0	58.6	9.0	780	6.0
CDC Teal CWRS	11.4	62.6	12.0	800	6.0
Sunstar APH	11.6	61.1	9.0	843	6.0
Norseman HRS	11.7	59.8	8.0	763	4.5
Glenlea CWES	12.6	63.0	26.5	795	9.5
Bluesky CWES	13.1	60.6	21.0	790	11.0
Wildcat CWES	14.0	63.7	20.0	898	9.0
Leader CWRS	14.3	64.0	11.0	865	5.5
Roblin CWRS	15.2	66.6	12.0	953	5.5

[a] CPS = Canada Prairie Spring; CWES = Canada Western Extra Strong Red Spring; CWRS = Canada Western Red Spring; HRS = Hard Red Spring (U.S.); APH = Australian Prime Hard.
[b] 14 % mb.
[c] Farinograph water absorption (FAB) with 2% NaCl.
[d] Farinograph dough development time (DDT) with 2% NaCl.
[e] Loaf volume. Means of triplicate analyses.
[f] DDT during bake mix in GRL-200 mixer. Means of triplicate analyses.

TABLE II
Texture Analyzer Test Using Three Hook Speeds on Dough Prepared at Farinograph Water Absorption (FAB) with 2% NaCl[a]

	3.3 mm/sec			7.0 mm/sec			10.0 mm/sec		
Wheat[b]	*A* (g·mm)	*E* (mm)	R_{max} (g)	*A* (g·mm)	*E* (mm)	R_{max} (g)	*A* (g·mm)	*E* (mm)	R_{max} (g)
Alpha 16	899g[c]	81fg	13.9f	1,413f	94e	19.2e	1,337f	80g	21.9g
Era	2,675a	119cd	36.5b	2,534a–c	109c–e	36.8bc	2,695bc	120cd	35.1cd
CDC Teal	1,513e	111d	22.6d	1,888d–f	121a–d	24.5de	2,173e	120cd	30.6de
Sunstar	1,560de	132ab	20.2d	2,118c–e	142a	25.3de	2,608b–d	149a	29.2ef
Norseman	1,252f	114d	17.2e	1,665ef	131a–c	19.1e	2,064e	133bc	24.9fg
Glenlea	1,900c	73g	45.3a	2,404b–d	100de	41.3b	2,790b	88fg	48.0b
Bluesky	2,157b	92e	39.1b	3,064a	93e	50.9a	3,402a	99ef	53.3a
Wildcat	1,668de	91ef	30.4c	2,687ab	111b–e	40.7b	2,318de	113de	36.5c
Leader	1,644de	125bc	22.8d	2,097c–e	134ab	27.5de	2,400c–e	136ab	31.9de
Roblin	1,761cd	139a	22.6d	2,427b–d	137ab	29.8cd	2,571b–d	146ab	29.6e

[a] Extensibility from start until dough rupture (*E*), area under the curve (*A*), and maximum resistance to extension (R_{max}).
[b] Samples arranged in increasing order of flour protein.
[c] Values followed by the same letter in the same column are not significantly different ($P < 0.05$). Means are based on triplicate analyses.

plots and general linear models (GLM) procedure on Statistical Application Systems software (SAS Institute Inc., Cary, NC). Data was normally distributed as tested by the normal plot (univariate procedure). The relative ranking of the samples, which measured relative differentiation between wheat samples, was obtained using GLM procedure and least significant difference (LSD) option. The relationship between the methods was established by Spearman rank correlation coefficient (r_s) (Hollander and Wolfe 1973) that measures the strength of the relationship between two methods based on the relative rank.

RESULTS AND DISCUSSION

The wheat cultivars in Sample Set 1, used for the optimization of hook speed on the TA and comparison of extensigraph and TA, varied widely with respect to protein content (8.6–15.2%, 14% mb), FAB (55–64%), and farinograph dough development time (DDT) (1.5–26.5 min). Table I gives the quality characteristics of these cultivars that ensured that the dough extension properties were determined for a wide range of protein quantity and quality.

Optimization of Hook Speed on the TA

The results for the effect of hook speeds at 3.3, 7.0, and 10.0 mm/sec on the extension properties as evaluated on the dough mixed at FAB (500 BU) are presented in Table II.

The R_{max} increased linearly to the increase of hook extension speed for some of the samples (Alpha 16, Sunstar, Norseman, and Leader), whereas other samples did not follow linear trends. The previous report of Prihoda and Bushuk (1971) showed a linear increase of stress with an increase of strain for a CWRS sample in a hook speed range of 1.0–9.0 mm/sec. Figure 1 illustrates the typical effect of increasing hook speed on the R_{max} for two wheats differing in dough strength (Alpha 16 and Glenlea). Weaker wheats such as the Alpha 16 breeders line showed ≈50% increase in the mean R_{max} value at the hook speed of 10.0 mm/sec as compared with R_{max} at 3.3 mm/sec. In similar comparisons, the stronger CWES wheats showed a smaller increase in the mean R_{max} value (6 and 20% for Glenlea and Wildcat, respectively).

Relative ranks based on R_{max} and area under the curve showed the most differentiation between wheats at the lower hook speed (3.3 mm/sec) as compared with the higher hook speeds of 7.0 and 10.0 mm/sec (Table II). Our results confirmed, therefore, that lower hook speed of 3.3 mm/sec, as recommended by manufacturer, should be applied in the extension test on the TA to obtain the optimum differentiation of wheats varying widely in dough rheological properties. Significant increase in the area under the extension curve with higher hook speed is a product of higher R_{max} and relatively constant dough extension.

Comparison of Extensigraph and TA

The interpretation of data from the extensigraph and the TA small-scale extensibility method, is complicated by the differences in the dough mass (75 g vs. 0.8 g), dough geometry (ratio of cross-section to length of dough stretched), as well as the differences in the hook speed (14.5 vs. 0–10 mm/s) for the extensigraph and the TA, respectively. The report of Prihoda and Bushuk (1971) showed a nonlinear (sigmoid) relationship between mass of the dough and R_{max} and a strong dependence of the individual slopes of the curve on the hook speed. Despite these differences, the extensigraph and TA extensibility methods were compared on the basis of 1) the ability to differentiate between wheat quality, and 2) the relationship to baking quality. Extensigraph data is presented in Table III.

The first comparison was determined by Spearman rank correlation coefficient (r_s) (Table IV) based on the data presented in Tables II and III. The extensigraph test after 45 min of rest time clearly distinguished the different wheats based on the area under the curve and R_{max} (Table III). The extension parameters obtained at 45 min of rest time were more reproducible compared with longer rest times (standard error of 1.0, 5.0, and 5.0 at 45 min of rest time compared with 5.0, 10.0, and 12.5 at 135 min of rest time for *A*, *E*, and R_{max}, respectively).These values are in agreement with findings of Muller and Hlynka (1964).

The high Spearman rank correlations between R_{max} on the extensigraph (45 min of rest time) and a TA (r_s = 0.90–0.99) were dependent on the hook speed. At a higher hook speed (10.0 mm/sec), the dough extension rates on the TA were similar to the extensigraph, as indicated by high rank correlation (r_s = 0.99). Rank correlations of *E* to *A* between the two instruments were substantially lower (Table IV).

In the second comparison, the dough tensile properties obtained on the extensigraph and TA were compared with the baking quality. LV range was 600–953 cm^3 (Table I) and correlated strongly to flour protein content (r = 0.91). The LV correlated poorly to dough extensibility on the extensigraph at 45 min of rest time and the TA at hook speeds 3.3, 7.0, and 10.0 mm/sec (r = 0.66, 0.54, 0.58, and 0.66, respectively). This poor relationship was attributed mainly to CWES wheats with low *E* and relatively high LV reported previously by Ingelin and Lukow (1998). When CWES cultivars were removed from statistical analyses, the Pearson correlation coefficients between LV and *E* for remaining samples from Set 1, were improved (r = 0.90, 0.96, 0.84, and 0.90, respectively, n = 7). The correlations indicate that *E* may be of practical use to predict LV if extra strong wheats are not included.

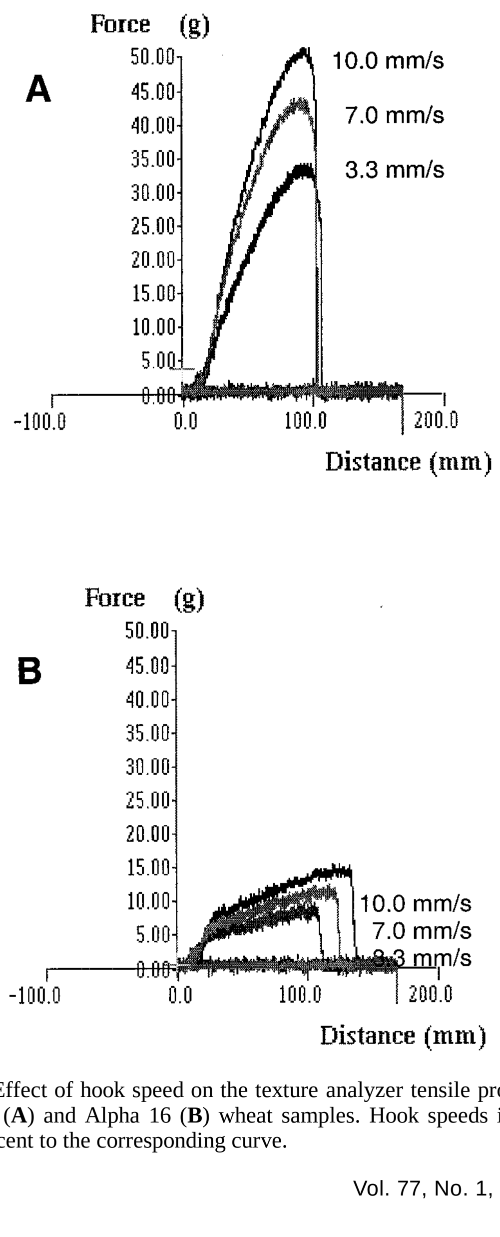

Fig. 1. Effect of hook speed on the texture analyzer tensile properties of Glenlea (**A**) and Alpha 16 (**B**) wheat samples. Hook speeds in mm/sec are adjacent to the corresponding curve.

TABLE III
Extensigraph Test Using Three Rest Times on Dough According to Approved Method 54-10[a,b]

Wheat[c]	45 min A (g·mm)	45 min E (mm)	45 min R_{max} (g)
Alpha 16	33g[d]	147e	167g
Era	93b	182bc	400c
CDC Teal	77c	195b	327d
Sunstar	55ef	192b	233f
Norseman	44fg	160de	225f
Glenlea	108a	146e	622a
Bluesky	117a	154de	632a
Wildcat	107a	167cd	508b
Leader	63de	182bc	288e
Roblin	73cd	216a	283e

Wheat[c]	90 min A (g·mm)	90 min E (mm)	90 min R_{max} (g)
Alpha 16	32f	140d	180e
Era	82d	142d	430c
CDC Teal	100bc	171b	460c
Sunstar	76d	173b	348d
Norseman	60e	146cd	330d
Glenlea	105b	95e	857a
Bluesky	131a	113e	880a
Wildcat	108b	168bc	532b
Leader	84d	171b	410c
Roblin	87cd	203a	345d

Wheat[c]	135 min A (g·mm)	135 min E (mm)	135 min R_{max} (g)
Alpha 16	36e	137c	203f
Era	90bc	136c	528c
CDC Teal	104b	173ab	470cd
Sunstar	81c	171ab	370de
Norseman	61d	141c	343e
Glenlea	90bc	77d	955a
Bluesky	93bc	86d	820b
Wildcat	125a	122c	857ab
Leader	84c	168b	413e
Roblin	98bc	191a	410de

[a] 75 g of dough tested (AACC 1995).
[b] Extensibility from start until dough rupture (*E*), area under the curve (*A*), and maximum resistance to extension (R_{max}).
[c] Samples arranged in increasing order of flour protein.
[d] Values followed by the same letter in the same column are not significantly different ($P < 0.05$). Means are based on triplicate analyses.

TABLE IV
Spearman Rank Correlation Coefficients (r_S) of Extensigraph Rest Time and Texture Analyzer Hook Speed[a]

Extensigraph Rest Time (min)	Hook Speed (mm/sec) 3.3	7.0	10.0
R_{max}			
45	0.95	0.90	0.99
90	0.89	0.83	0.95
135	0.94	0.87	0.95
E			
45	0.83	0.76	0.80
90	0.81	0.91	0.86
135	0.76	0.79	0.75
A			
45	0.82	0.83	0.73
90	0.61	0.76	0.55
135	0.48	0.65	0.27
R_{max}/E			
45	0.89	0.71	0.71
90	0.88	0.67	0.70
135	0.89	0.71	0.71

[a] Extensibility from start until dough rupture (*E*), under the curve (*A*), and viscoelastic ratio determined by the ratio of maximum resistance to extension (R_{max}) to extension (R_{max}/E).

TABLE V
Means and Standard Error of Extension Parameters on a Texture Analyzer for Sample Set 2[a]

Type[b]	Absorption (%)	R_{max} (g)	*E* (mm)	*A* (g·mm)
FAB	65.9 ± 0.5b[c]	24.8 ± 1.2a	122 ± 3a	1,713 ± 65a
FAB+6%	71.9 ± 0.5a	15.0 ± 0.8b	127 ± 6a	1,054 ± 37b
MAB	69.7 ± 0.8a	16.2 ± 0.9b	121 ± 2a	1,199 ± 53b

[a] Extensibility from start until dough rupture (*E*), area under the curve (*A*), and maximum resistance to extension (R_{max}). Hook speed 3.3 mm/sec; ($n = 29$).
[b] Farinograph water absorption (FAB); optimized flour absorption for a 2-g mixograph (MAB) with 2% NaCl.
[c] Values followed by the same letter in the same column are not significantly different ($P < 0.05$). Means are based on duplicate analyses.

Evaluation of Microextension Method at Different Flour Absorptions

A larger wheat sample set (Sample Set 2, $n = 29$, Table V) was used to evaluate the effect of different water absorptions such as FAB, FAB+6%, and 2-g MAB on the dough extension properties. The mean extension properties of the doughs, prepared in the 2-g mixograph at three different water absorptions and tested on a TA at a hook speed of 3.3 mm/sec are presented in Table V. The reproducibility of TA extension parameters from Sample Set 2, as measured by standard error of the overall mean, was comparable to Sample Set 1.

Water content of the dough was positively related to *E* and negatively related to the R_{max}. Doughs prepared at FAB had significantly higher ($P \leq 0.05$) mean R_{max} values and areas under the curve as compared with doughs prepared at higher absorptions (FAB+6% and MAB), (Table V). Higher rank correlations of the R_{max}, *E*, and R_{max}/E (r_s = 0.89, 0.75 and 0.91, respectively) obtained at FAB+6% and MAB absorptions as compared with FAB absorption, indicated that the water level affected significantly the wheat sample rank.

Sample ranking based on *E* at FAB, FAB+6%, and MAB correlated positively to sample ranking based on LV (r_s = 0.69, 0.77, and 0.74, respectively), whereas ranking based on the R_{max} correlated negatively to LV (r_s = –0.75, –0.72, and –0.72, respectively). R_{max}/E correlated negatively to LV (r_s = –0.77, –0.76, and –0.77, for FAB, FAB+6%, and MAB, respectively). R_{max} for Sample Set 2 was highly correlated (r = 0.85–0.89) to the GRL-200 mixer dough development time at all the three water absorptions investigated but showed negative relationship to LV (r = -0.67 to –0.77), depending on the dough water content. A similar trend was also observed in Sample Set 1, where the R_{max} was highly correlated to dough development time on GRL-200 mixer but not correlated to LV. However, Bloksma (1990) and Kieffer et al (1998) reported that R_{max} may be correlated highly and positively with LV.

Based on the ability to differentiate between samples with different dough physical properties and the relationship of tensile parameters to LV, any of the three investigated absorptions (FAB, FAB+6%, or MAB) can be used to prepare the dough for small-scale extensibility tests using the 2-g mixograph and a TA. However, dough water content at FAB is not recommended for stronger wheats like Glenlea, where the presence of 2% salt results in a stiff dough. The stiffening effect of salt can be compensated for by using FAB+6 % water that would allow the dough to be readily mixed in the 2-g mixograph (Ingelin and Lukow 1998). Because there is no significant difference in extension properties for dough prepared at FAB+6% and MAB, both water levels could be used in a TA extension test.

Applying a Microextensibility Method

The baking potential of small quantities of bread wheat flour can be determined by mixing 2 g of sample in a 2-g mixograph at FAB+6% or MAB and by measuring the extension properties on a TA. The small-scale nature of the test requires that the water content in dough and the temperature be strictly controlled to obtain consistent and reliable results.

During an 8-hr period, 10–12 samples can be tested. This is double the amount usually tested on an extensigraph. The dough microextensibility method is valuable primarily in research and early-generation wheat quality screening where the amount of available sample does not allow testing by the standard extensigraph method. The value of the small-scale dough extensibility test for prediction of LV is promising. However, the effect of a full formula dough on the relationship between dough extensibility parameters and LV remains to be investigated. Prediction of LV from dough extensibility parameters may be improved by including flour protein content in the multiple regression analyses, as suggested by Weipert (1991).

CONCLUSIONS

A small-scale dough extension method using a 2-g mixograph and a TA was outlined that offers significant savings of sample material and time and yields valuable information about dough tensile properties and baking potential. The optimal hook speed on a TA instrument for the best quality differentiation among wheat samples with a wide range of quality was confirmed at 3.3 mm/sec. When the Brabender extensigraph and TA.XT2 texture analyzer were compared, the results indicated that R_{max} was the most reproducible parameter and correlated best between the two instruments. The small-scale extensibility method investigated at FAB+6% and MAB absorptions differentiated effectively among wheat samples on the basis of E, R_{max}, and R_{max}/E. The R_{max} correlated best to GRL-200 dough development time, reflecting closely the dough mixing requirements and strength.

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