

# Mixing Properties, Baking Potential, and Functionality Changes in Storage Proteins During Dough Development of Triticale-Wheat Flour Blends

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## ABSTRACT

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Flours from advanced lines or cultivars of six triticales and two prime hard wheats, along with triticale-wheat blends, were investigated for mixing, extension (excluding blends), and baking properties using microscale testing. Percentage total polymeric protein (PPP) and percentage unextractable polymeric protein (UPP) of flours and doughs, including blends, mixed to optimal dough development were estimated using size-exclusion HPLC to determine the changes in protein solubility and association with blend composition (BC), mixing properties, and loaf height. Each triticale was blended with flours of each of the two wheat cultivars (Hartog and Sunco) at 0, 30, 40, 50, 60, 70, and 100% of wheat flour. Nonlinear relationships between BC and mixograph parameters (mixing time [MT], bandwidth at peak resistance [BWPR], and resistance breakdown [RBD]) were observed. A linear relationship between BC and peak resistance (PR) was predominant. PPP of triticale flours was mostly higher than PPP of wheat cultivars. UPP of all triticales was significantly lower than wheat cul-

vars. PPP of freeze-dried doughs was mostly nonsignificant across the blends and showed a curvilinear relationship with BC. The deviations from linearity of MT and PPP were higher in triticale-Sunco blends than in triticale-Hartog blends. UPP of blends was closer to or lower than the lower component in the blend. The deviations from linearity for MT and UPP were greater in triticale-Hartog blends than triticale-Sunco blends. A highly significant correlation ( $P < 0.001$ ) was observed between BWPR and loaf height. This suggested that BWPR in triticale-wheat flour blends could be successfully used for the prediction of loaf height. Triticale flour could be substituted for wheat flour up to 50% in the blend without drastically affecting bread quality. Dough properties of triticale-wheat flour blends were highly cultivar specific and dependent on blend composition. This strongly suggested that any flour blend must be tested at the desired blend composition.

Secondary hexaploid triticale (*X Triticosecale* Wittmack) is currently a commercially successful triticale. It is high yielding and well adapted to extreme cold, drought, and acidic soils. It is grown in almost all geographic regions where the parental species are grown. The area under triticale cultivation is increasing steadily all over the world (Varughese et al 1996), which seems to indicate that triticale will join other cereals to provide food to the rapidly growing human population.

In breadmaking, the physical properties of dough determine the quality of the finished product. The quantity and quality of gluten largely determine these physical properties. Triticale gluten is widely perceived to be weak, with consequent poor dough-handling properties (Pena and Ballance 1987), such as high levels of dough stickiness and poor baking potential. Some of the present day triticales have good breadmaking potential that may be regarded as exceptions to this assumption (Amaya et al 1986). From a nutritional point of view, triticale has certain valuable dietary characteristics such as higher amounts of soluble dietary fiber (Villegas et al 1970) and better overall amino acid composition, in particular higher lysine, than wheat (Morey and Evans 1983).

Given these advantages, as well as agronomic potential, it can be concluded that triticale has all the vital quality attributes of a food cereal and should become an important food cereal in the near future. One possible approach to improve bread quality could be blending triticale flour with wheat flour. Earlier studies showed that addition of up to 30% of triticale flour resulted in satisfactory bread. A more recent study (Pena and Amaya 1992) indicated that breads of acceptable quality, although significantly different from bread baked with wheat flour, could be produced with 1:1 blends of triticale-wheat flour. Reexamining the data of Pena and Amaya (1992) (Fig. 1) shows that bread volume is not proportional to the amount of triticale flour in the blend. The addition of even 50% triticale flour had a negligible effect on loaf volume. This implies that when triticale and

wheat flour are blended together, the baking performance is a nonlinear function of the blend composition (BC). While the data from these workers encompassed only two composite flours of triticale cultivars, it suggested that this type of nonlinearity was a widespread phenomenon.

Dough development during mixing is the phase of the breadmaking process where gluten functionality is critical. As mixing proceeds, the initial incoherent dough mass develops viscoelastic properties. Gluten proteins form a matrix defined both by chemical bonds and physical entanglements. Protein solubility and major changes in the gluten complex take place before the optimal dough development (Bushuk et al 1997). It seems likely that to understand the processes taking place during mixing and baking, it would be necessary to study the changes occurring in the polymeric protein of developing dough. Previous studies in this area focus on wheat (MacRitchie 1975; Danno and Hosoney 1982; Weegels et al 1996; Bushuk et al 1997), but there are no reports regarding mixing properties and changes in polymeric protein of triticale and triticale-wheat flour blends.

The flour quality parameters of cultivars or advanced lines of six triticales and two wheats were investigated. The triticale flours were each blended at several levels with each of the two prime hard Australian wheat cultivars. Wheat cultivars were current high-quality bread wheats that differed at *Glu-1* loci. Mixing properties, changes in soluble and insoluble protein concentration of doughs, and loaf height were evaluated for each of the triticales, wheats, and triticale-wheat blends.

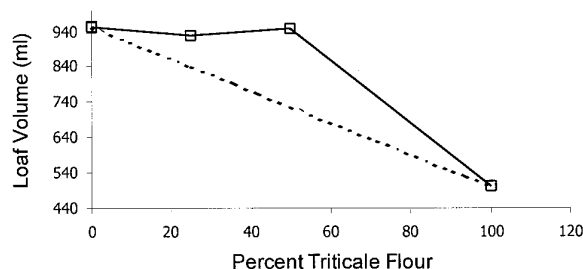


Fig. 1. Relationship between percentage of triticale flour in triticale-wheat flour blends and loaf volume.

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## MATERIALS AND METHODS

### Plant Material

Cultivars or advanced lines of six secondary hexaploid ( $2n = 42$ ) spring triticales and two prime hard Australian wheat cultivars, Sunco and Hartog, were selected for this study (Table I). Tahara and Abacus are commercial triticale cultivars in Australia, D12/Tatu was locally bred, and the other three triticale lines were selections from CIMMYT quality nurseries. All of the triticale cultivars and advanced lines were grown at the Department of Agriculture, New South Wales Research Station at Cowra, during the growing season 1996. The grain samples of Sunco were kindly provided by Frank Ellison, I. A. Watson Wheat Research Centre, Narrabri. All triticales and Sunco were milled into flour on a Quadrumat Jr. flour mill. The flour of Hartog was supplied by Lindsay O'Brien, I. A. Watson Wheat Research Centre, Narrabri.

### Physicochemical Characteristics of Flours

Flour samples were analyzed for nitrogen percentage by the Dumas total-combustion method in an elemental analyzer (CHN-1000, Leco Inc., St. Joseph, MO). Nitrogen percentage was used to compute protein content ( $N\% \times 5.7$ ) and the results were adjusted to 13.5% moisture.

Damaged starch and flour ash content of the sample set were determined at Bread Research Institute, North Ryde, Australia. SDS sedimentation (SDSS) volume was determined in quadruplicate for each sample (Silvela et al 1993). Stirring number was determined on a Rapid Visco Analyser (RVA). All tests were performed at least in duplicate unless otherwise mentioned.

### Relative Size Distribution of Polymeric Protein by SE-HPLC

The percentage of total polymeric protein in protein (PPP) and percentage of unextractable polymeric protein (UPP) were measured by SE-HPLC (Gupta et al 1993) using a modified protein extrac-

tion procedure. After protein extraction, the sample was centrifuged at  $20,800 \times g$  for 10 min and filtered through a  $0.45\text{-}\mu\text{m}$  nylon filter. The filtrate was heated in a water bath at  $70^\circ\text{C}$  for 2 min to inactivate proteases (Larroque et al 2000). The samples were then immediately cooled with chilled water. The total protein was also separated into two size fractions: extractable (without sonication) and unextractable (extractable only after sonication). In Fig. 2, chromatogram area of triticale chromatogram was multiplied by a factor (chromatogram area of wheat divided by chromatogram area of triticale) to equalize area in both chromatograms to facilitate the comparison of different peaks.

Similarly, PPP and UPP of freeze-dried doughs from all flour blends including 0, 30, 40, 50, 60, 70, and 100% triticale flour were determined. For this purpose, flour and flour blends were mixed with water to the previously determined MT. This dough was then frozen ( $-80^\circ\text{C}$ ), freeze-dried, and crushed into fine powder with a pestle and mortar. This powder (10 mg) was then analyzed for PPP and UPP using SE-HPLC (Gupta et al 1993). Each test was performed in duplicate.

### Rheological and Baking Properties

Flours were mixed in a 2-g mixograph (National Manufacturing, Lincoln, NE) to determine the optimum mixing time (MT). Quantities of flour and water were calculated according to Approved Method 54-40A (AACC 2000) at variable moisture. Mixing properties, mixing time (sec), peak resistance (arbitrary units [au]), bandwidth at peak resistance (au), and resistance breakdown (%) were measured. Mixing was done at least in duplicate. Mixing properties were also examined for the triticale-wheat flour blends containing 0, 30, 40, 50, 60, 70, and 100% of triticale flour.

Dough extensibility of triticale and wheat flours excluding blends was determined using a small-scale extension test (Rath et al 1994). Mixing time for extension tests was determined using a standard formulation containing 2% NaCl based on the weight of flour. Quan-

TABLE I  
Physicochemical Characteristics of Advanced Lines or Cultivars of Six Triticales and Two Wheats<sup>a</sup>

Cultivar or Line	FP	Ash	DS	SN	Ext	R <sub>max</sub>
Wheat	12.83a <sup>b</sup>	0.47de	1.5de	108.77a	11.67a	0.42b
Sunco	12.47b	0.42f	2.1c	107.54a	10.72ab	0.45a
Hartog						
Triticale	4.96g	0.49cd	1.6de	35.52d	3.76e	0.10de
Abacus	5.51f	0.45e	2.8b	78.12b	5.31d	0.23c
Tahara	7.76e	0.58a	2.9b	57.86c	6.41c	0.09ef
LC838 Anoas3/Tatu4//Erizo11*2/Milan	5.53f	0.49cd	4.0a	19.77e	4.91d	0.12d
LC427 Anoas3/Tatu4	9.24d	0.55ab	1.7d	85.98b	10.29b	0.12d
LC314 Anoas3/Tatu4	10.47c	0.53b	1.4e	81.80b	10.0b	0.08f
Least significant difference ( $P < 0.05$ ).	0.12	0.03	0.2	9.24	0.96	0.02

<sup>a</sup> FP = flour protein, DS = damaged starch, SN = stirring number (RVU), Ext = dough extensibility (cm), and R<sub>max</sub> = dough maximum resistance.

<sup>b</sup> Values followed by the same letter in the same column are not significantly different ( $P < 0.05$ ).

TABLE II  
SDS Sedimentation Volume and % Area Under Different Peaks of Size-Exclusion HPLC Chromatograms of Advanced Lines or Cultivars of Six Triticales and Two Wheats<sup>a,b</sup>

Cultivar or Line	Peak 1	Peak 2	Peak 3	UPP	SDSS
Wheat					
Sunco	51.62c <sup>c</sup>	37.50b	10.89g	49.37b	10.1a
Hartog	46.04h	41.58a	10.17h	53.12a	10.3a
Triticale					
Abacus	48.11g	33.62c	18.27a	24.02e	1.5f
Tahara	56.83a	28.81d	14.37c	34.29c	1.9ef
LC838 Anoas3/Tatu4//Erizo11*2/Milan	49.44f	37.54b	13.03d	29.27d	2.7d
LC427 Anoas3/Tatu4	54.42b	29.39d	16.21b	28.14d	2.3de
LC314 Anoas3/Tatu4	50.36e	37.74b	11.90e	33.24c	4.1b
D12/Tatu	50.45d	37.89b	11.68f	34.99c	3.4c
Least significant difference ( $P < 0.05$ ).	0.60	0.80	0.25	2.47	0.40

<sup>a</sup> Peaks 1–3: % polymeric protein, gliadin, and albumin-globulin, respectively.

<sup>b</sup> UPP = % unextractable polymeric protein, SDSS = SDS sedimentation (mL).

<sup>c</sup> Values followed by the same letter in the same column are not significantly different ( $P < 0.05$ ).

ties of flour and water were determined according to Approved Method 54-10 (AACC 2000) and scaled to produce 3.5 g of dough per mix. Extension tests were performed in triplicate.

Micro loaves were prepared in quadruplicate for the whole sample set using a rapid dough formulation containing 2% salt, 0.5% improver (formulated to include 100 ppm of ascorbic acid), and 2.5% compressed yeast based on the weight of flour. After mixing to peak dough development, dough (2.4 g/loaf) was rested (30 min at 40°C and 90% rh), molded, proofed (45 min at 40°C and 90% rh), and baked in a tunnel oven at 200°C for 17 min. The baked loaves were cooled on the tabletop for almost 2 hr before loaf height was measured.

**Statistical Analysis**

Data were analyzed by statistical software (v. 6.12 for Windows, SAS Institute, Cary, NC) using analysis of variance (general linear model). Means were compared using the least significant difference (LSD) test at 5% level of significance.

**TABLE III**  
Mixing Parameters of Six Triticales, One Wheat (cv. Sunco), and Triticale-Wheat Flour Blends<sup>a</sup>

Blend (%)	MT	PR	BWPR	RBD
Wheat flour				
Sunco (100%)	310.0c-f <sup>b</sup>	503.7a	321.7a	12.0e-j
Triticale flour				
Abacus				
30	319.3bc	388.7h-k	226.0f-k	11.7e-j
40	298.3d-h	362.7k-m	215.3i-l	13.3d-i
50	283.0h-m	336.0no	198.7l-n	12.0e-i
60	292.3e-i	299.3p	176.7no	13.7d-i
70	280.0h-m	259.7q	145.3pq	21.0a-c
100	131.0q	171.0st	108.5s	5.5lm
Tahara				
30	277.7i-n	416.0d-f	278.7bc	8.3i-m
40	295.0d-i	379.0kl	249.7d-f	7.3i-m
50	313.3b-d	326.7o	216.0h-l	5.7lm
60	312.3cd	289.0p	213.0i-m	5.3lm
70	291.0f-j	255.3qr	186.7m-o	6.3k-m
100	205.7o	191.0s	139.0p-r	9.0i-m
LC838 Anoa3/Tatu4/Erizo11*/Milan				
30	265.0mn	421.3de	266.3cd	10.3g-l
40	264.0mn	408.3e-i	251.3d-f	13.0d-i
50	269.3lmn	385.7i-l	226.7f-k	13.3d-i
60	267.3mn	353.3mn	186.7m-o	17.7b-d
70	281.0h-m	337.0mn	165.5op	21.0a-c
100	219.3o	232.0qr	116.0rs	25.0a
LC427 Anoa3/Tatu4				
30	312.3cd	424.3de	281.7bc	6.7i-m
40	294.7d-i	387.0h-k	250.0d-f	6.0lm
50	297.0d-i	343.3m-o	200.0k-n	6.3k-m
60	283.3h-m	300.7p	201.7j-n	4.3m
70	265.3mn	246.3qr	180.3no	15.3d-g
100	180.3p	162.0t	114.3rs	13.5d-i
LC314 Anoa3/Tatu4				
30	290.0g-k	453.3bc	309.7a	9.3d-g
40	289.0g-l	438.5cd	295.5ab	9.0i-m
50	311.0c-e	410.3e-h	259.7c-e	10.7g-l
60	332.3ab	390.3g-k	235.3e-i	10.0h-l
70	299.3d-h	379.7kl	246.3d-g	6.3k-m
100	345.7a	259.0q	127.5q-s	14.5d-i
D12/Tatu				
30	307.0c-g	477.3b	268.0cd	7.0i-m
40	271.3j-n	436.7cd	242.3d-h	12.0g-j
50	271.0k-n	411.3e-g	227.3f-j	16.0e-j
60	263.7mn	397.0f-k	210.0i-m	16.7c-g
70	259.3n	405.7e-j	195.3l-n	22.3ab
100	210.0o	384.0j-l	229.0f-i	17.0b-e
LSD <sup>c</sup>	19.7	24.1	26.7	5.4

<sup>a</sup> MT = mixing time, PR = peak resistance, BWPR = bandwidth at peak resistance, RBD = resistance breakdown.

<sup>b</sup> Values followed by the same letter in the same column are not significantly different ( $P < 0.05$ ).

<sup>c</sup> Least significant difference ( $P < 0.05$ ).

**General Characteristics**

The flour protein content, ash, and starch damage are shown in Table I. All the triticales had significantly lower protein and stirring number (SN) than wheat cultivars. LC427 had high starch damage (4.0) and low SN (19.8) compared with other lines in the sample set, and certainly would be unacceptable for commercial baking. Both wheat cultivars had higher SN values than the triticale cultivars and lines.

All triticales had weaker dough than wheat, as indicated by the dough maximum resistance ( $R_{max}$ ). Dough extensibility of LC314 and D12/Tatu was similar to that of Hartog. Abacus had the least extensible dough (Table I). Extensibility was highly correlated ( $r = 0.96$ ,  $P > 0.001$ ) with flour protein content and flour polymeric protein ( $r = 0.97$ ,  $P > 0.001$ ), respectively. Significant correlation between  $R_{max}$  and flour polymeric protein was also observed ( $r = 0.66$ ,  $P > 0.001$ ). Similar observations were reported for dough extensibility and  $R_{max}$  in wheat (Gupta et al 1993).

**TABLE IV**  
Mixing parameters of Six Triticales, One Wheat (cv. Hartog), and Triticale-Wheat Flour Blends<sup>a</sup>

Blend (%)	MT	PR	BWPR	RBD
Wheat flour				
Hartog (100%)	317.5bc <sup>b</sup>	466.0a	306.5a	5.5n-p
Triticale flour				
Abacus				
30	282.5f-i	414.5f-h	269.0e	3.0p-r
40	270.5j-l	374.0k-m	244.0gh	2.0r
50	270.7i-l	361.0mn	22.0i-m	8.3k-n
60	238.5n	312.5p	194.5o	19.0b
70	225.5o	282.0q	174.0p	19.5b
100	131.0r	171.0u	108.5s	5.5n-p
Tahara				
30	287.5e-g	407.0g-i	266.5ef	7.5lm
40	266.0kl	386.5jk	269.0e	6.0no
50	281.0g-j	356.5n	238.5g-j	6.5m-o
60	294.5ef	336.5o	214.5l-n	16.0c-e
70	289.0e-g	312.0p	197.0o	23.0a
100	205.7p	191.0t	139.0q	9.0j-m
LC838 Anoa3/Tatu4/Erizo11*/Milan				
30	316.0bc	424.0d-f	263.0ef	6.0no
40	315.0bc	420.5e-g	241.5g-i	9.5i-l
50	284.5f-h	394.0ij	223.0j-m	10.5h-k
60	274.5h-j	370.5l-n	194.5o	13.0f-h
70	260.5k-m	365.5mn	189.5op	14.0e-g
100	219.3op	232.0s	116.0rs	25.0a
LC427 Anoa3/Tatu4				
30	265.0kl	432.0de	285.5cd	6.5m-o
40	272.5h-k	393.0ij	252.0fg	8.0k-n
50	252.5m	370.5l-n	244.0gh	17.5bc
60	259.5lm	341.0o	219.5k-m	24.0a
70	271.5i-l	309.5p	197.0o	24.5a
100	180.3q	162.0v	114.3rs	13.5e-g
LC314 Anoa3/Tatu4				
30	307.0cd	450.5b	297.5a-c	4.0o-r
40	279.0g-j	435.0cd	287.5b-d	2.5qr
50	309.0b-d	427.0d-f	277.0de	5.0o-q
60	297.5de	403.5hi	241.0g-i	5.5n-p
70	284.0f-h	382.0j-l	234.0h-k	7.5l-n
100	345.7a	259.0r	127.5qr	14.5d-f
D12/Tatu				
30	317.0bc	469.5a	302.5ab	4.0o-r
40	320.0b	469.0a	266.5ef	9.5i-l
50	298.5de	450.0bc	233.0h-k	11.5g-j
60	298.5de	426.0d-f	213.0mn	12.0f-i
70	284.5f-h	429.0d-f	203.5no	17.0b-d
100	210.0p	384.0jk	229.0h-l	17.0b-d
LSD <sup>c</sup>	12.4	14.4	15.7	2.8

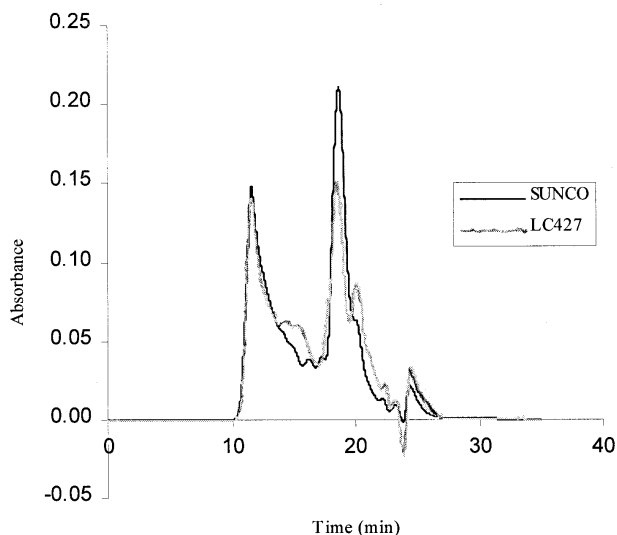
<sup>a</sup> MT = mixing time, PR = peak resistance, BWPR = bandwidth at peak resistance, RBD = resistance breakdown.

<sup>b</sup> Values followed by the same letter in the same column are not significantly different ( $P < 0.05$ ).

<sup>c</sup> Least significant difference ( $P < 0.05$ ).

### Quantification of Unreduced Flour Protein

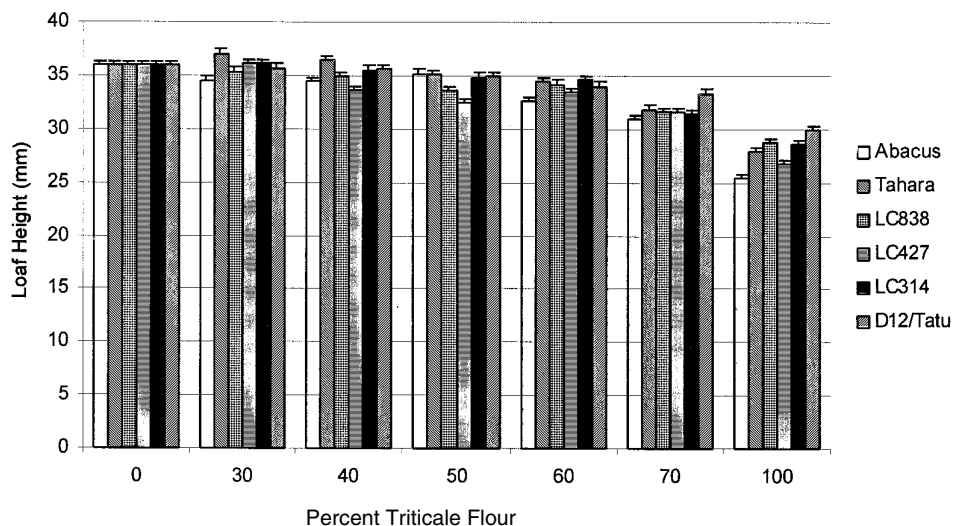
Proteins from the triticales and wheat flours were fractionated into three main peaks using SE-HPLC (Table II). In the order of elution, they were 1) polymeric, 2) gliadins, and 3) albumin-globu-



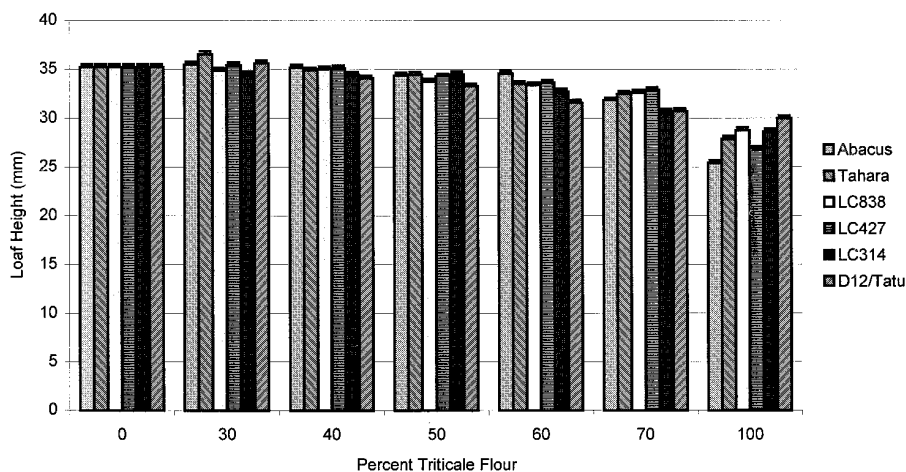
**Fig. 2.** Size-exclusion HPLC profiles of total protein of tritcale (LC427) and wheat (Sunco).

lins (MacRitchie 1992). All triticales had significantly higher PPP than Hartog. Tahara and LC427 had significantly higher PPP than the wheat standards. Hartog had significantly higher proportions of gliadin than the Sunco and all triticales. However, nonsignificant differences were observed for gliadin proportions between Sunco and three triticales (LC838, LC314, and D12/Tatu). Both wheat cultivars had significantly lower proportions of albumins-globulins compared with triticales. The higher values of PPP for triticales should be treated with caution. A close examination of peak-1 of wheat and tritcale chromatograms revealed differences in shape of the two chromatograms (Fig. 2).

Peak-1 of the wheat chromatogram was an almost smooth curve but this was not true for tritcale chromatogram. The different shape of the tritcale chromatogram indicated a difference in molecular weight distribution of polymers. The polymeric protein that eluted up to 13.2 min in the tritcale chromatogram constituted 52–56% area of peak-1 compared with 59–60% area of peak-1 in the wheat chromatogram, which was a difference of 4–8% in peak-1 area. Change of peak-1 area (1%) due to high molecular weight subunits in wheat is associated with a change of 27 BU in  $R_{max}$ , 0.5 cm in extension, and 0.6 min in MT, whereas the same change in low molecular weight is associated with 6 BU, 0.2 cm, and 0.1 min for the same parameters (MacRitchie 1992). Such a difference in tritcale would be more pronounced due to the presence of rye secalins that have a significantly negative impact on quality parameters (Dhaliwal et al 1987; Graybosch et al 1993). Proteins eluting toward the end of peak-1 in the tritcale chromatograms may be below the molecular



**Fig. 3.** Loaf height of tritcale-Sunco flour blends.



**Fig. 4.** Loaf height of tritcale-Hartog flour blends.

size threshold needed to form effective entanglements necessary for dough strength. It has been reported that maximum dough resistance in wheat had the strongest correlation with PPP that eluted up to 13.2 min before the highest molecular weight proteins (Bangur et al 1997). These proteins are estimated to correspond to molecular weights of  $\geq 250,000$ . A glutenin of this size could contain one high molecular weight and four low molecular weight subunits. Extensibility was affected by molecular size distribution to a lesser extent than  $R_{max}$ .

All the triticals had significantly higher proportions of PPP than Hartog, but markedly lower proportions of UPP than Sunco and Hartog (Table II). Among the triticals, Tahara had significantly higher amounts of PPP than D12/Tatu and LC314, but the differences in UPP for these samples were statistically nonsignificant (Table II).

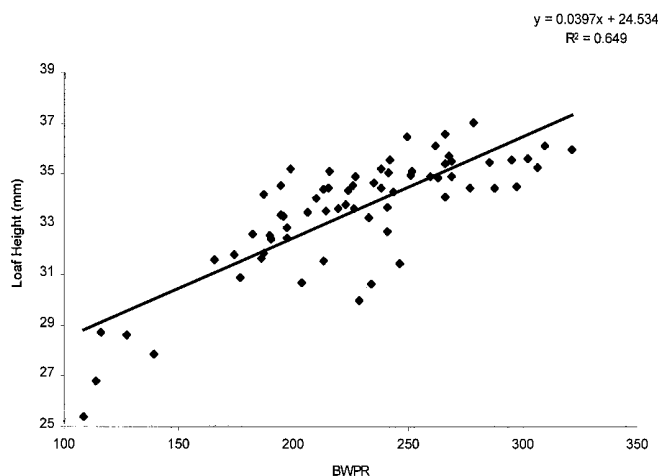


Fig. 5. Correlation between bandwidth at peak resistance (BWPR) and leaf height.

SDSS volume is also a measure of insoluble protein content like UPP. Abacus, Tahara, and LC427 had similar flour protein content, but significant differences were found for SDSS volume and UPP. A different ranking was observed for SDSS volume and UPP in the present sample set. This difference in ranking may be related to the different distribution of high molecular weight polymers suspected from the differences in the peak-1 profile.

### Mixing Time

Generally, the triticals had shorter mixing times than wheat (Tables III and IV) with the exception of LC314, which had a significantly longer mixing time than the wheat cultivars.

The mixing times of the triticale-wheat flour blends varied with the source of triticale and wheat flour used, and the blend composition. The MT pattern was only vaguely similar to the weighted means of MT of the blend components. Tahara and LC314 had unique and unusual mixing behavior in blends with Sunco. The other four triticals exhibited a curvilinear relationship in the blends.

D12/Tatu and LC838 could both be blended with Hartog up to 40% without any significant decrease in MT from Hartog itself (Table IV). Increase in the proportion of Abacus, D12/Tatu, and LC838 flour in the blend resulted in a continuous decrease in MT. When LC838 flour in the blend was increased to 50%, MT dropped sharply. At higher levels of LC838, a linear relationship for MT was observed. Mixing time decreased significantly with the addition of 30% of triticale flour from Abacus, Tahara, LC314, and LC427. In blends of Hartog with Tahara, LC314, or LC427, the changes in MT resulting from changes in composition of blend were erratic. This nonlinear behavior may be due to an increase in the proportion of smaller polymers consequent to addition of triticale flour. This susceptibility to the presence of low molecular weight material is a well-established phenomenon in polymer science.

Small changes in the quantities of components at the ends of the molecular weight spectrum cause disproportionately large effects on physical properties (MacRitchie 1984). Bekes et al (1998) reported a nonlinear relationship for mixing properties of wheat flour blends.

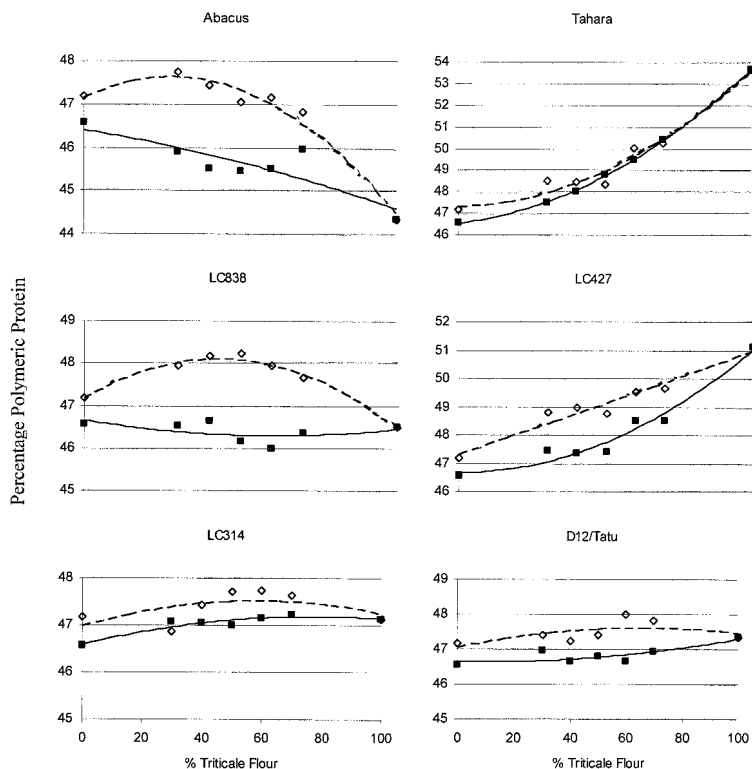


Fig. 6. Relationship between flour composition and total polymeric proteins of freeze-dried dough ( $\diamond$  triticale-Sunco flour blends and  $\blacksquare$  triticale-Hartog flour blends).

They investigated the effect of flour *Glu-1* subunit composition on mixing properties. The *Glu-D1d* (5+10) made a major contribution toward deviations from linearity. In the present study, the *Glu-1* subunit composition of Hartog was *Glu-A1a* (1), *Glu-B11* (17+18), and *Glu-D1d* (5+10), and that of Sunco was *Glu-A1a* (1), *Glu-B1b* (7+8), and *Glu-D1a* (2+12). According to the *Glu-1* scoring system, Hartog has a quality score of 10 and Sunco has a quality score of 9 (Payne et al 1987). The major difference between these two cultivars contributing to the *Glu-1* quality score was at the *Glu-D1* locus. In the present study, the deviation from linearity in MT was higher for blends with Sunco, which has genes for the expression of 2+12 subunits. This is in contrast to a recent observation (Bekes et al 1998), where mixing properties of wheat flour blends were examined. The deviations from linearity were greater for flours containing subunits 5+10 than for flours containing 2+12. The nonlinear response of MT to the changes in BC shows that triticale flours must be tested at the intended composition of the desired triticale-wheat flour blend.

### Peak Resistance

Peak resistance (PR) of triticale-Sunco blends was inversely related to BC for all triticales, except D12/Tatu, which showed a nonlinear relationship with BC. Curvilinear relationships were also observed between PR and BC for Hartog blends with LC838, LC314, and D12/Tatu, whereas linear relationships were observed for blends of Hartog with Abacus, Tahara, and LC427 (Tables III and IV).

### Bandwidth at Peak Resistance

Bandwidth at peak resistance (BWPR) reflects the total flour composition including all flour constituents of polymeric and monomeric proteins. It also provides a measure of the changing extensional viscosity in the dough during mixing (Gras et al 2000). BWPR is, thus, an estimate of the  $R_{max}$  that would be obtained in a micro-extension test. In this study, BWPR was closely related to the observed  $R_{max}$ . Using data from six triticales and two wheats (excluding blends),  $r = 0.84$  ( $P > 0.01$ ) for the relationship between BWPR and  $R_{max}$ .

In most cases, BWPR was inversely proportional to the amount of triticale flour in the blend with Sunco. The only exception noted

was for D12/Tatu, where BWPR of D12/Tatu (100%) was significantly greater than the 70% blend with Sunco.

Linear relationships were observed for BWPR and percentage of triticale flour in blends with Hartog for all triticale cultivars and lines except D12/Tatu and LC314, where a curvilinear relationship was observed.

### Resistance to Breakdown

A continuous decrease in RBD (as expected) was observed in blends with Sunco with all triticales containing up to 60% of triticale flour, except Abacus (Table III). At higher levels, RBD for blends containing these triticales deviated from the expected linear behavior to a greater or lesser degree. However, in blends containing 30–60% Abacus, no significant change in RBD was observed.

Two patterns were also observed for RBD in blends with Hartog (Table IV). An increase in RBD with the increase of triticale flour in the blend was observed for LC838 and D12/Tatu. In blends with Abacus, Tahara, and LC427, RBD remained unchanged to a certain blend composition and then increased at higher levels of triticale flour in the blend. RBD of pure triticales Abacus, Tahara, and LC427 was lower than the respective 70% blend with Hartog. This behavior of the triticales is not consistent in blends with the two wheat flours.

### Micro Loaves

Loaves produced from pure triticale flour were significantly smaller than those from Sunco and Hartog (Fig. 3). A wide variation in loaf height among the triticale loaves was observed (25.4–30.0 mm). As observed for mixing properties, PPP, and UPP, loaf height of various blends was highly cultivar-dependent. Flour from Tahara and D12/Tatu could be used up to a level of 40% in blends with Sunco without significantly affecting the loaf height. An increase of triticale flour from Tahara, LC314, and D12/Tatu in blends up to 60% produced breads with acceptable loaf height, although significantly different from Sunco. An unusual result was the significant increase in loaf height with 30% Tahara flour in the blends with Sunco and Hartog, whereas a significant decrease in MT was observed for the same flour blend. This unusual behavior needs further study.

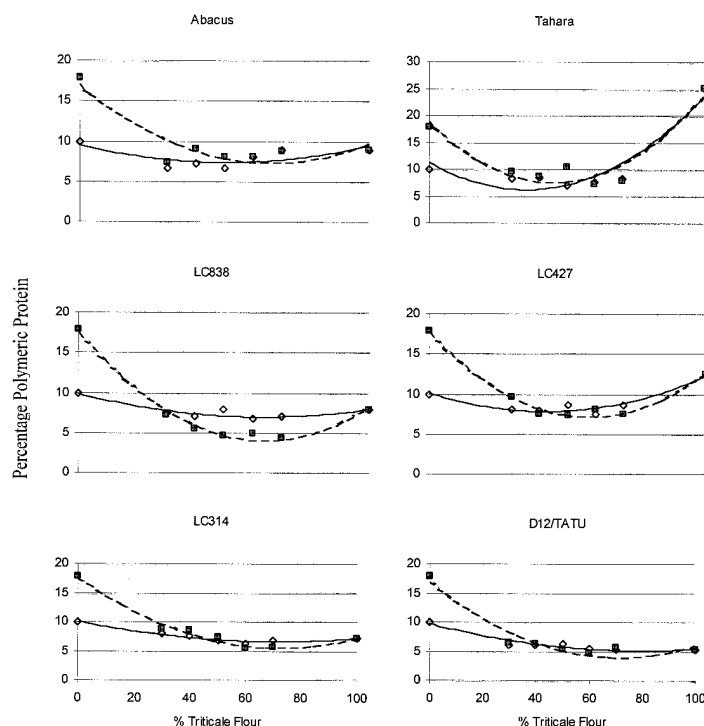


Fig. 7. Relationship between flour composition and unextractable polymeric protein (UPP) of freeze-dried dough ( $\diamond$  triticale-Sunco flour blends and  $\blacksquare$  triticale-Hartog flour blends).

Triticale-Hartog flour blends with 30, 40, and 50% LC314 produced loaves that were not significantly different from each other but were significantly different from Hartog (Fig. 4). Loaves of acceptable height were produced with blends containing up to 60% Abacus, 50% Tahara, LC314, and LC427, and 40% D12/Tatu and LC838.

### BWPR Predicting Loaf Height

Eleven of the 12 relationships of BWPR and loaf height were significant ( $P > 0.05$  or  $0.01$ ). The relationship for D12/Tatu-Sunco blends was nonsignificant ( $r = 0.58$ ), and the loaf volume of the pure triticale unduly influenced this relationship. Linear regression between BWPR and loaf height for results from all blends of each triticale were highly significant ( $r = 0.805$ ,  $P < 0.001$ ,  $n = 68$ ) (Fig. 5). The line of best fit ( $R^2 = 0.649$ ) was:

$$Y = 24.534 + 0.0397x$$

where  $Y$  = loaf height (mm) and  $x$  = BWPR (au). The standard deviations of the slope and intercept were 0.004 and 0.838, respectively.

No correlation between loaf height and MT, PR, or RBD was observed. This confirms a previous observation where no correlation was found between loaf volume and MT for a sample of 135 wheat lines (Dong et al 1992).

### PPP and UPP of Freeze-Dried Dough

To further investigate the nonlinear behavior of triticale-wheat flour blends for mixing properties and baking potential, PPP and UPP of the freeze-dried dough of each of the triticales, triticale-wheat blends, and wheats were determined. PPP values of freeze-dried doughs were lower than the corresponding values for flour (Table II, Fig. 6). This indicated a decrease in protein extractability after mixing. Similar findings have been reported for wheat (Borneo and Khan 1999), where wheat flour and water were mixed to optimal dough development with 2% (flour wt) sodium chloride. Polymeric protein was then analyzed by SE-HPLC. In contrast, Weegels et al (1996) observed increased protein extractability after mixing; all the flours were mixed to a fixed MT. The residual protein was determined by the Kjeldahl method. They hypothesized that mixing caused depolymerization by physical separation and breaking covalent or noncovalent bonds. It should be noted that dough was not mixed to optimal dough development.

Correlation between PPP and MT, PR, and BWPR were mostly significant in blends of Sunco or Hartog with Tahara, LC427, or Abacus (Tables V and VI). These are the three triticales that had very low flour protein content. The observed correlation may thus represent measures of the predominantly wheat protein in these blends. For the other three triticale blends that had higher flour protein content, the correlations were statistically nonsignificant.

The relationship between PPP and composition of flour blend was statistically improved by adding a quadratic term to the regression, confirming that the relationship between the parameters was nonlinear rather than nonexistent. Deviations from linearity for PPP versus blend composition were higher for triticale-Sunco blends than triticale-Hartog blends (Fig. 6).

In the blends, the UPP was very low in all cases. In fact, the levels were much lower than could be expected by a linear estimate of UPP based on the UPP of dough from the components (Table II, Fig. 7). As with PPP, a strongly curved (nonlinear) relationship was observed between UPP and BC. The deviation from linearity was more pronounced in blends with Hartog than with Sunco. In contrast, deviation from linearity was greater for MT in triticale-Sunco blends. It appears that this nonlinearity is somehow related to glutenin subunit composition and needs further investigation to understand protein interactions in triticale-wheat blends.

## CONCLUSIONS

The results of this study show that the mixing and baking behavior of triticale-wheat flour blends are a nonlinear combination of mixing and baking properties of the parent flours. The degree of nonlinearity is a function of both the proportion and the source of triticale and wheat flour components. The results show that selection of triticales for use in blends with wheat must be based on tests using the desired blend of triticale and wheat.

The amounts of PPP and UPP of freeze-dried dough mixed to peak dough development time were also nonlinear functions of the amounts of these materials in doughs made from the pure components. This implies that interaction between the proteins of the component flours during mixing and baking is different from the interactions between the proteins of triticale or wheat alone. Despite the nonlinearity of response to the blend components, BWPR provided a promising measure of baking potential for all blends.

TABLE V  
Correlation Coefficients of Total Polymeric Protein of Triticale-Wheat Flour Blends for Mixing Parameters and Loaf Height<sup>a,b</sup>

Cultivar or Line	MT		PR		BWPR		RBD		LH	
	H	S	H	S	H	S	H	S	H	S
Abacus	0.87*	0.96**	0.85*	0.73	0.84*	0.69	0.08	0.62	0.78*	0.91**
Tahara	0.83*	0.83*	0.99**	0.92**	0.98**	0.93**	0.39	0.54	0.96**	0.94**
LC838 Anoa3/Tatu4/Erizo11*/Milan	0.28	0.34	0.14	0.40	0.28	0.35	0.13	0.67	0.11	0.62
LC427 Anoa3/Tatu4	0.92**	0.86*	0.98**	0.95**	0.97**	0.94**	0.38	0.10	0.96**	0.87*
LC314 Anoa3/Tatu4	0.21	0.15	0.52	0.10	0.52	0.13	0.25	0.45	0.61	0.04
D12/Tatu	0.24	0.21	0.86*	0.24	0.72	0.53	0.30	0.70	0.57	0.22

<sup>a</sup> MT = mixing time, PR = peak resistance, BWPR = bandwidth at peak resistance, RBD = resistance breakdown, LH = loaf height. H = Hartog, S = Sunco.

<sup>b</sup> \*, \*\* significant at  $P > 0.05$  and  $0.01$ , respectively.

TABLE VI  
Correlation Coefficients of Unextractable Polymeric Protein of Triticale-Wheat Flour Blends for Mixing Parameters and Loaf Height<sup>a,b</sup>

Cultivar or Line	MT		PR		BWPR		RBD		LH	
	H	S	H	S	H	S	H	S	H	S
Abacus	0.44	0.34	0.50	0.19	0.53	0.28	0.23	0.40	0.17	0.21
Tahara	0.58	0.94**	0.42	0.53	0.35	0.59	0.38	0.00	0.65	0.82*
LC838 Anoa3/Tatu4/Erizo11*/Milan	0.33	0.46	0.36	0.52	0.55	0.56	0.32	0.23	0.23	0.23
LC427 Anoa3/Tatu4	0.24	0.78*	0.21	0.37	0.24	0.37	0.56	0.42	0.07	0.68
LC314 Anoa3/Tatu4	0.23	0.24	0.46	0.58	0.47	0.52	0.18	0.44	0.53	0.38
D12/Tatu	0.34	0.67	0.42	0.82*	0.67	0.91**	0.54	0.42	0.54	0.55

<sup>a</sup> MT = mixing time, PR = peak resistance, BWPR = bandwidth at peak resistance, RBD = resistance breakdown, LH = loaf height. H = Hartog, S = Sunco.

<sup>b</sup> \*, \*\* significant at  $P > 0.05$  and  $0.01$ , respectively.

Triticale cultivars and advanced lines (Tahara and D12/Tatu), although of relatively poor baking performance themselves, may be blended into wheats at levels as high as 50% without adversely affecting baking performance.

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