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Alveoconsistograph evaluation of rheological properties of rye doughs

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Abstract

The aim of this work is to study the effect of rye flour on the rheological properties of doughs. Rye meals of two different extraction rate (65% and 85%) were blended in different proportions with wheat flours. The viscoelastic behaviour of the sample blends was determined by a Chopin alveograph. The effect of rye flour on dough rheology during mixing was determined by a Chopin consistograph. It was found that Chopin Consistograph methodology was not suitable for determining water absorption capacity in blends with rye. It has been confirmed that adjustment of dough hydration in baked products incorporating rye flour must be taken into account, depending not only on the wheat-to-rye ratio but also on the rye meals extraction rate.

Additional key words: alveo-consistograph, Chopin methodology, dough rheology, *Secale cereale*.

Resumen

Evaluación de las propiedades reológicas de masas con centeno mediante el empleo de alveoconsistógrafo

El objeto de este trabajo es el estudio de la influencia del empleo de harina de centeno sobre las propiedades reológicas de las masas panarias. Para ello, se ensayaron dos harinas de centeno de diferente tasa de extracción (65% y 85%) mezcladas en diferentes proporciones con harina de trigo. Las propiedades viscoelásticas de las mezclas se determinaron mediante el alveógrafo de Chopin y para analizar su comportamiento durante el amasado se utilizó el consistógrafo de Chopin. Se concluye que la metodología Chopin para el consistógrafo no es apropiada para determinar la capacidad de absorción de agua de masas con centeno. Se confirma la necesidad de reajustar la hidratación de la masa cuando se incluyen harinas de centeno en su formulación, en función tanto de la proporción de harina de centeno como de su tasa de extracción.

Palabras clave adicionales: alveo-consistógrafo, metodología Chopin, reología, *Secale cereale*.

Introduction

Rye (*Secale cereale* L.), after wheat, is the second most commonly used grain in the production of bread (Bushuk, 2001). The most important factors in rye baking are the quality of starch and cell wall material and the activities of endogenous enzymes modifying them (Vanhamel *et al*., 1993; Autio *et al*., 1997; Weipert, 1997; Jiang *et al*., 2005; Salmenkallio-Marttila and Hovinen, 2005). The major rye cell wall components —

Abbreviations used: AACC (American Association of Cereal Chemists), AH (adapted hydratation), AX (arabinoxylans), CH (constant hydratation), db (dry base), D250 (drop in pressure at 250 s), D450 (drop in pressure at 450 s), FN (falling number), F1 (first factorial axis), F2 (second factorial axis), HYD2200 (water absorption capacity), ICC (International Association for Cereal Science and Technology), L (extensibility), P (tenacity), PCA (principal component analysis), PrMax (maximum pressure), R1 (rye flour with an extraction rate of 65%), R2 (rye flour with an extraction rate of 85%), Tol (tolerance), TprMax (time, in s, to reach maximum pressure), W (deformation energy), w60 (weight of dough at 60 s).

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arabinoxylans (AX) — have high water binding capacity and produce an important effect on both gas retention and rheological properties of dough (Vinks and Delcour, 1996; Autio *et al.*, 1997; Fabritius *et al.*, 1997; Lorenz, 2000) as well as on texture and other end-product quality characteristics (Izydorczyk and Biliaderis, 1995; Vinkx and Delcour, 1996; Weipert, 1997).

Furthermore, high content of AX, and especially high content of water soluble AX, have been found to be positively correlated with rye baking quality (Vinkx *et al.*, 1995; Weipert, 1995; Vinkx and Delcour, 1996; Salmenkallio-Marttila and Hovinen, 2005).

Comparison of the viscoelastic parameters obtained from wheat doughs with those of rye doughs points up the greater rigidity of rye doughs (Fabritius *et al*., 1997). Rheological differences depend on both the surface area of insoluble cell walls and particle size distribution (Autio *et al*., 1997, 1999). The latter is related to the extraction rate of rye flours. The rather high volume fraction of particles in rye dough and the considerable particle rigidity significantly affect dough rheology.

Otherwise, unlike wheat, rye is sold in lots with no cultivar information. In view of the low sprouting resistance of rye, evaluation of rye flour is based on amylogram data and alpha-amylase activity expressed in falling number (FN) or amylograph units (Meuser *et al.,* 1994; Weipert, 1997; Autio *et al*., 1999; Hansen *et al*., 2004; Salmenkallio-Marttila and Hovinen, 2005). The AX component, which controls dough and volume yield, has so far been neglected. FN for rye within the range of 120-160 seconds is generally considered to be satisfactory. This corresponds to amylogram gelatinization temperatures of 64-66ºC. However, no strong relationship between FN and amylogram gelatinization temperature has yet been found (Meuser *et al*., 1994; Fabritius *et al*., 1997).

The aim of this work is to study the use of Chopin alveoconsistograph for analyzing the rheological properties of doughs elaborated with blends of wheat and rye flours in different proportions. Rye flours of two different extraction rates were analyzed. An overview of the relationships between the various parameters measured of the different blends was obtained using principal component analysis (PCA).

Material and methods

Flour samples

Commercial wheat (Harinera de Salvanés, Madrid, España) and rye flours (Harinas Esteban, Valladolid, España) were used. Wheat flour contained 13.9% moisture, 12.0% db (dry base) dry gluten, 37.0% wet gluten and 99.3 gluten index. Dry and wet gluten were determined by standard method ICC 155 (ICC, 1996) and gluten index with the Glutomatic System method AACC 38-12 (AACC, 2000). Rye flour was obtained from a German hybrid cultivar APART grown in Renedo de Esgueva (Valladolid). Rye grain moisture was 8.11% and its specific weight was 78.50 kg hL^{-1}. Two different rye flours were used: rye flour with an extraction rate of 65% (R1) and rye flour R2 with an extraction rate of 85% (R2).

Samples of flour blends

Wheat and rye flours were blended for rheological analysis. Selected ratios of wheat-to-rye flour used in blend samples and their abbreviations are presented in Table 1.

Rheological measurements

The viscoelastic behaviour of sample blends was determined by an alveograph NG-97 (Tripette et Renaud, France), following the standard method AACC 54-30 (AACC, 2000). Monitored parameters were the deformation energy (W), tenacity or resistance to extension (P) and dough extensibility (L).

The effect of rye flour on dough rheology during mixing was determined by a consistograph (Tripette et Renaud, France) following the standard method AACC 54-50 (AACC, 2000). Parameters recorded were: maximum pressure (PrMax); water absorption capacity (HYD2200, water required to yield dough consistency equivalent to 2200 mb of pressure measured at constant hydratation); time, in s, to reach maximum pressure (TprMax); time, in s, for the pressure to rise above PrMax minus 20% or tolerance (Tol); the drop in pressure at 250 s from PrMax minus 20% (D250); and the drop in pressure at 450 seconds from PrMax minus 20% (D450).

Viscoelasticity of sample blends was determined according to the following: 1) mixing of dough in the alveograph mixer, following the standard protocol of the alveograph method; 2) extraction of mixed dough through the dispenser of the alveograph mixer during a constant time of 60 s; and 3) weighing the amount of dough extracted through the dispenser in a precision

Table 1. Wheat-to-rye ratios of flour blend samples

Sample code	Wheat flour in the blend (% weight)	Rye flour in the blend (% weight)	Rye flour extraction rate (%)
100W	100	0	-
90W:10R1	90	10	65
80W:20R1	80	20	65
70W:30R1	70	30	65
60W:40R1	60	40	65
50W:50R1	50	50	65
90W:10R2	90	10	85
80W:20R2	80	20	85
70W:30R2	70	30	85
60W:40R2	60	40	85
50W:50R2	50	50	85

balance. The monitored parameter was weight (g) of dough at 60 s (w60).

Falling number (FN) of sample blends was measured by standard method 107/1 ICC (ICC, 1996).

Statistical analysis

Correlation analysis was performed in order to establish the relationships between parameters, by using Pearson's correlation coefficient. Rheological parameters from the eleven blends were submitted to principal component analysis (PCA) in order to reduce the dimensionality of the data matrix. Software used for both analyses was STATBOX Agri Version 6.7.

Results and Discussion

Rheological properties of selected ratios of wheat-to-rye flour blend samples are summarized in Table 2. As the amount of rye flour in the blend increases, P increas-

Table 2. Rheological properties of selected ratios of wheat-to- rye flour blend samples

Samples	FN (s)	Alveogram			Consistogram						w60 (g)
					CH		AH				
		W (10^{-4}J)	P (mm)	L(mm)	PrMax (mb)	HYD2200 (%)	TPrMax (s)	Tol (s)	D250 (mb)	D450 (mb)	
100W	440.5	401	93	105	2,912	53.5	112	224	373	1,196	35.39
90W:10R1	413.5	343	97	91	2,653	53.2	144	236	243	1,053	34.00
90W:10R2	391.0	357	104	86	2,663	52.4	123	220	392	1,198	37.43
80W:20R1	395.0	323	108	81	2,820	53.9	98	208	419	1,120	33.46
80W:20R2	393.0	322	109	78	2,535	52.1	98	195	473	1,138	34.30
70W:30R1	362.0	266	112	66	2,553	52.8	106	177	541	1,134	32.46
70W:30R2	386.0	231	110	55	2,601	53.0	127	208	369	1,132	33.01
60W:40R1	385.0	217	117	50	2,302	51.6	126	148	657	1,280	32.33
60W:40R2	388.0	186	114	41	2,221	50.1	112	130	946	1,469	32.68
50W:50R1	368.0	156	116	34	2,348	51.8	104	126	953	1,463	30.82
50W:50R2	358.5	155	118	33	1,937	50.0	100	121	985	1,404	32.43

AH: adapted hydratation, CH: constant hydratation; FN: falling number, D250:drop in pressure at 250 seconds, D450: drop in pressure at 450 seconds, HYD2200: water absorption capacity, L: extensibility, P: tenacity, Prmax: maximum pressure, Tol: tolerance, TprMax: time in seconds to reach maximum pressure, W: deformation energy, w60: weight of dough at 60 seconds.

es and L decreases. The resulting effect on P and L becomes evident in the P/L ratio value, making for increasingly unbalanced doughs.

Increase of rye flour in the blend is linked to a decrease of the deformation energy (W), and, in most cases, to a decrease of both maximum pressure (PrMax) and water absorption capacity of the blend (HYD2200), for both extraction rate flours R1 and R2. Similar values of these three parameters were observed in blends with sorgo-to-wheat by Hernández and Jova (2001), rice-to-wheat by Caballero (2001), maize-to-wheat by Gavilán *et al.* (2004) and by del Real (2005) and, more recently, with barley-to-wheat by Chaya *et al.* (2008) and oat-to-wheat by Callejo *et al.* (2009).

A decrease in W due to the decrease of gluten content of the blends was observed and reported by other authors (Quaglia, 1991; Kulp and Ponte, 2000) as might be expected. Nevertheless, an increase in rye flour content should be expected to increase the water absorption parameter (HYD2200), because rye cell wall components have a greater waterholding capacity. In fact, increases in water absorption were observed by other authors using farinograph instead of consistograph and by adding 5% of rye bran supplement (Laurikainen *et al.,* 1998), carob and pea fibre (Wang *et al.*, 2002), water soluble and water insoluble pentosans of wheat and water-soluble pentosans of rye (Michniewicz *et al*., 1991). No such increases in water absorption were observed with the addition of inuline (Wang *et al*., 2002).

Previous studies (Chopin, 2000) demonstrated that although water absorption capacity as determined by the consistograph method appears to be lower than results from the farinograph method, the two method results are well correlated, and have been found in studies of wheat flours. Moreover, even though the cell component content is greater in the R2 rye flours than in the R1, HYD2200 is lower in R2 blends for a given substitution rate, suggesting that the decrease of this parameter could be due to the difficulty of hydration of the rye cell wall components in the consistograph mixer.

These results suggest that Chopin methodology for the consistograph could be inappropriate for high fibre doughs. In fact, Chopin suggests carrying out the test at 55% instead of 50% constant hydratation for the analysis of high fibre wheat flours (Chopin, 2004).

Concerning the other parameters studied, with increasing rye flour proportion in the blend, drops in pressure at 250 s and at 450 s (D250 and D450, respectively) become greater, while tolerance (Tol) decreases. Faridi (1985), Quaglia (1991) and Kulp and Ponte (2000) suggested that tolerance, determined with farinograph, is correlated with amount of gluten, that decreases with an increase in rye flour content.

Related to the influence of rye flour on blend viscosity, with increasing rye flour content, the w60 parameter decreases; that is, viscosity increases. This could be due to the high viscosity of soluble AX (Autio *et al.,* 1997; Courtin *et al.,* 2001). The only exception to this general result is dough 90W:10R2 which exhibits the lowest viscosity (highest value of w60). For a given substitution rate, R2 rye blends induced higher w60 (less viscosity) than R1 blends. Autio *et al.* (1999) suggested that, not only total pentosans (whose major components are AX), but also flour particle size and soluble pentosans are correlated with rheological properties of doughs. This could be the reason for a decrease in viscosity for the R2 blends.

Generally, sample blends of lower extraction rate rye flours (R1) have better rheological properties than higher extraction rate rye flours (R2). A higher extraction rate increases bran concentration of flours, which has been found to weaken viscoelastic properties of wheat gluten (Salovaara and Autio, 2001).

FN parameter decreases as rye flour content of dough increases, due to the greater alpha-amylasic activity of rye compared to that of wheat flour. Wheat flours with FN within the range 200-250 seconds are suitable (Quaglia, 1991) while, for instance in Germany, rye flour used for baking has FN within the range 120-160 seconds (Meuser *et al.*, 1994). It should be noted, however, that the sourdough process, used in the breadmaking of most rye breads (Kujala, 2005) induces a pH decrease (Arendt *et al.*, 2007).

Looking at the correlation coefficients obtained from the different doughs studied, presented in Table 3, several comments are appropiate. Correlation coefficients are mostly significant and very high, attaining even the maximum value (1) between variables W and L, indicating a direct linear relationship of W with L.

A significant negative correlation (-0.92) between L (dough extensibility) and P (dough resistance to deformation or tenacity) was found. Parameters PrMAx, Hyd2200 and W are positively correlated. Besides the high positive correlation between PrMax and HYD2200 (0.94) there is a positive correlation between PrMax and W (0.87). There is a high positive correlation between Tol and W (0.91) and between Tol and L (0.92).

Due to the high correlation coefficients observed, the two first Principal Components explain a high pro-

Table 3. Rheological parameter correlation coefficients. See parameters definition in Table 2. In bold: significant values (except diagonal) at the alpha=0.05 level of significance (two-tailed test)

	W	P	L	PrMax	HYD2200	TPrMax	Tol	D250	D450	w60
W	1	**-0.89**	**1.00**	**0.87**	**0.75**	0.22	**0.91**	**-0.86**	**-0.76**	**0.82**
P	**-0.89**	1	**-0.92**	**-0.81**	**-0.68**	-0.40	**-0.86**	**0.78**	**0.62**	**-0.70**
L	**1.00**	**-0.92**	1	**0.88**	**0.77**	0.25	**0.92**	**-0.87**	**-0.77**	**0.78**
PrMax	**0.87**	**-0.81**	**0.88**	1	**0.94**	0.19	**0.89**	**-0.86**	**-0.75**	0.57
HYD2200	**0.75**	**-0.68**	**0.77**	**0.94**	1	0.22	**0.84**	**-0.86**	**-0.82**	0.37
TPrMax	0.22	-0.40	0.25	0.19	0.22	1	0.43	-0.47	-0.34	0.25
Tol	**0.91**	**-0.86**	**0.92**	**0.89**	**0.84**	0.43	1	**-0.98**	**-0.89**	**0.73**
D250	**-0.86**	**0.78**	**-0.87**	**-0.86**	**-0.86**	-0.47	**-0.98**	1	**0.95**	**-0.64**
D450	**-0.76**	**0.62**	**-0.77**	**-0.75**	**-0.82**	-0.34	**-0.89**	**0.95**	1	-0.48
w60	**0.82**	**-0.70**	**0.78**	0.57	0.37	0.25	**0.73**	**-0.64**	-0.48	1

portion of data variation (76% and 10% respectively). Correlation coefficients between the rheological parameters and the two first principal components are presented in Figure 1. The first principal component is positively correlated with W, L, PrMax, Tol, HYD2200 and w60 and negatively correlated with D250, D450 and P.

Figure 2 shows the blend samples projection over the first factorial plot (F2 *vs* F1). The first principal component may be interpreted as a measure of the amount and quality of protein. Samples with high wheat-to-rye ratio in the blend (100W, 90W:10R1, 90W:10R2, 80W:20R1, 80W:20R2, 70W:30R1 and 70W:30R2) with higher gluten content and better breadmaking performance, appear on the right, whereas samples with higher levels of rye in the blend (60W:40R1, 60W:40R2, 50W:50R1 and 50W:50R2) appear on the left.

The influence of rye flour on viscoelastic characteristics and mixing properties is more pronounced with rye flour extraction rate R2. This is shown in Figure 2, where the R2 samples are generally located to the left of the R1 samples for a given substitution rate.

The second principal component is highly correlated with the parameter TprMax (0.91) determined by the consistograph; no other variable is correlated with it. This parameter does not show any pattern of dependence on the wheat-to-rye ratio in the blend nor on the extraction rate of rye flour. This could be due to rye AX interference in wheat gluten hydratation, which would cause disturbances of the time to reach the maximum sample pressure.

It may be concluded that Chopin consistograph methodology was not suitable for determining water absorption capacity in blends with rye. So dough hydra-

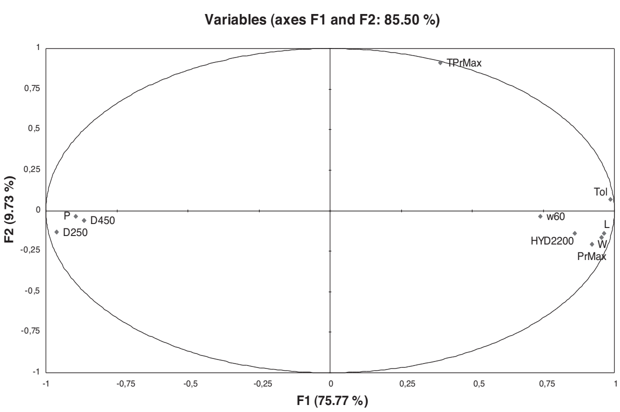

Figure 1. Correlation coefficients between variables (see definitions in Table 2) and the two first factorial axis (F2 *vs* F1).

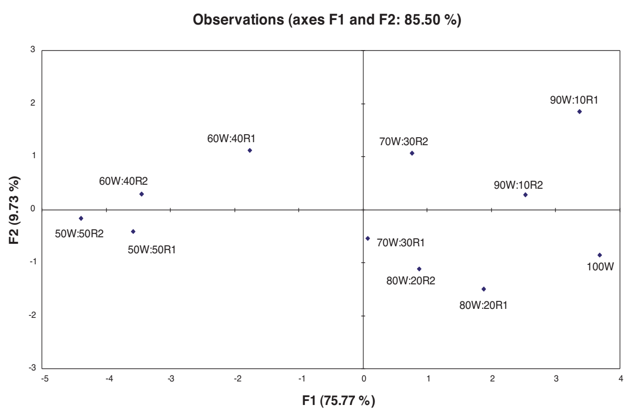

Figure 2. Projection of sample blends (see codes in Table 1) over the first factorial plot (F2 *vs* F1).

tion in baked products incorporating rye flour must be taken adjusted for, depending not only on the wheat-to-rye ratio but also on the rye meal extraction rate.

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