International Journal of
Food Science & Technology

International Journal of Food Science and Technology 2010, **45**, 697–706

Original article

Use of wheat, triticale and rye flours in layer cake production

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(Received 30 October 2009; Accepted in revised form 7 January 2010)

Abstract In this study, the capacity of obtaining high quality layer cakes from rye and triticale lines was analysed and compared to wheat lines. The samples were characterised considering grain hardness, flour composition and quality parameters as protein, pentosan, damaged starch, pasting viscosity and functional predictive test – solvent retention capacity test. Cakes were analysed in weight, symmetry, volume, volume index (VI) by measuring the height in different points of the cake, crust and crumb colour, crumb structure and texture. Wheat and triticale cakes showed similar characteristics. Rye cakes showed higher volume and lower weight than those with crumbs darker in colour, higher adhesiveness, springiness and resilience. The multiple regression analysis was used to develop an equation for cake volume index prediction. The best-fit linear regression model was: $VI = 14.75 - 0.14 \times \text{protein} + 0.93 \times \text{water soluble pentosan} - 0.27 \times \text{total pentosan}$. Despite the differences, high quality cakes can be elaborated with rye, triticale and soft wheat cultivars.

Keywords Layer cake, rye, triticale, wheat.

Introduction

In areas of the world where disease or untoward soil conditions restrict wheat production, alternative crops must be developed for human consumption. In addition, these alternative crops offer the industry the opportunity of using new ingredients and diversify the production. In this sense attempts are being made to enrich bread and bakery products with non-wheat flour such as non-wheat cereals, oilseeds, tubers, nuts or legumes (Chavan & Kadam, 1993).

Considering non-wheat cereals, rye and triticale show very attractive agronomic properties such as hardiness, vigour, yield capacity and disease resistance (Wu *et al.*, 1978). Moreover, rye and triticale show interesting nutritional characteristics. Rye endosperm has higher proportion of pentosans and other wall polysaccharides than wheat (Henry, 1987; Dervilly-Pinel *et al.*, 2001). On the other hand, rye and triticale are characterised by containing higher α-amylase activity, lower gluten content than wheat (Aguirre *et al.*, 2002; Ragaee & Abdel-Aal, 2006) and lower damaged starch content than hard wheat (Kruger *et al.*, 1998; Moiraghi *et al.*, 2005; Roccia *et al.*, 2006). With regard to proteins, it was determined that rye and triticale proteins showed higher biological value than wheat (Kies & Fox, 1970). Fibre is known to have beneficial effects against diseases such as obesity, cardiovascular disease, hypercholesterolemia, digestive problems and cancer (Jones, 2008). In a Finnish study, the reduction of risk of cardiovascular disease was associated with the increase of rye products intake (Pietinen *et al.*, 1996). Lærke *et al.* (2008) have indicated in a recent study that rye fibre reduce the level of cholesterol in a higher extent than wheat fibre. The beneficial effect of fibre in rye is attributed to its water-binding capacity and its inhibitions of the absorption of saturated fatty acids and sodium (Åman *et al.*, 1997). Because of the influence of these compounds, the technological properties of dough and batter and thus the quality of the finished products are modified. Arabinoxylans are known to absorb large amounts of water, about ten times their weight in water and influence significantly the water balance and the rheological properties of dough (Muralikrishna & Subba Rao, 2007). Damaged starch and gluten absorb large quantity of water and have a negative influence in soft wheat products quality (Slade & Levine, 1994). The higher content of free amino acids results in a richer flavour due to Maillard reaction. The amylolitic consumption of starch, apart from affecting flavour and colour after baking, influences viscosity and pasting properties of their flours during processing (Ragaee & Abdel-Aal, 2006). In general, the rheological properties and the overall gluten strength of dough obtained from rye and triticale are lower and stickiness is higher than

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doi:10.1111/j.1365-2621.2010.02183.x

wheat dough (Peña & Amaya, 1992). That is why the elaboration of products that need weak flour without an extensive gluten network (cookies, crackers, cakes and *tortillas*) is an interesting use for these grains (Gaines, 1990).

Despite technological differences, rye (second to wheat), is the most commonly used grain in the production of bread (Bushuk, 2001). Other bakery products such as cookies (Ragaee & Abdel-Aal, 2006) and wafer crackers (Hempel *et al*., 2007) have been also prepared with rye. In the case of triticale, important results in the elaboration of cookies (León *et al*., 1996; Roccia *et al*., 2006) and crackers (Pérez *et al*., 2003) have been obtained. In addition, Tsen (1974) affirmed that acceptable pancakes, doughnuts and muffins can also be successfully prepared.

Relating to cake elaboration, substitution of wheat flour with 30% of rye whole grain meal had no significant effects on quality (Ragaee & Abdel-Aal, 2006). Acceptable white layer cakes with good symmetry and uniformity were made from triticale flour replaced with more than 40% standard cake flour (Tsen, 1974). Despite the works about wheat replacement, little information exists about the quality of cakes only elaborated with rye or triticale flours and the effect of cultivar.

The solvent retention capacity (SRC) profile (Approved Method 56-11; AACC International, 2000), is a modified test from the alkaline water retention capacity test (Approved Method 56-10; AACC International, 2000). The use of four solvents was extended further to clarify functional components of flour by Slade and Levine (1994). Distilled water reflects the ability of flour to hold water; sucrose solution differentiates flours with differing water-soluble pentosans; sodium carbonate solution is sensitive to swelling of damaged starch and pentosans in flour; and lactic acid acts to swell the glutenin subunits that reflect the strength of a dough (Gaines, 2000; Guttieri *et al*., 2001; Ram & Singh, 2003; Roccia *et al*., 2006). To date, research on SRC test has been mainly focused on cookies, crackers and some sweet goods that are primarily made from soft wheat flour (Slade & Levine, 1994; Gaines *et al*., 2000; Guttieri *et al*., 2001; 2002, 2004; Ram & Singh 2004), although SRC test have been used to predict cookie quality from triticale and hard wheat flour (Roccia *et al*., 2006; Colombo *et al*., 2008). SRC is a rapid test to characterise flour functionality. Cake quality depends on batter viscosity and stability for obtaining a sponged structure that does not collapse. The batter properties are related to starch, pentosan and protein characteristics of flour, so the SRC can be a good estimator of cake quality. Recently Nishio *et al*. (2009) have found significantly correlations between SRC values and cake volume in non-waxy and partial waxy near isogenic wheat lines.

More studies to determine the aptitude of different rye and triticale cultivars to elaborate cakes with 100% of these flours are required. In the present study, different rye cultivars and triticale experimental lines have been characterised and compared with wheat experimental lines. Their capacity to obtain high quality layer cakes has also been analysed.

Materials and methods

Materials

Four experimental wheat lines – TS19, TS44, TS52, TS53, four hexaploid triticale lines – TT1003, TT1037, TT1039, TT1041 and four commercial rye cultivars – Camilo (tetraploid), Don Guillermo (tetraploid), Fausto (diploid), Lisandro (diploid) were used. All wheat lines, excepted TS44, have 1BL/1RS translocation from rye.

Triticale, wheat lines and rye cultivars were provided by Estación Experimental Agropecuaria, Marcos Juarez y Bordenave from Instituto Nacional de Tecnología Agropecuaria (INTA) Argentina. Grains were milled at approximately 58% flour yield in a four-roller laboratory mill (Agromatic AG AQC 109, Laupen, Switzerland). Sucrose, sunflower oil, milk, fresh whole eggs and double-action baking powder were purchased from the local market.

Grain and flour characteristics

Grain hardness was determined by the particle size index (PSI) following the Approved Method 55-30 (AACC, 2000). The Agromatic AG AQC 109 mill (Laupen, Switzerland) was used. The result was calculated as the relative weight of sieved flour × 100 and compared with a table to attain relative hardness.

The protein content was obtained by a micro Kjeldahl method modified with boric acid (Approved Method 46-13; American Association of Cereal Chemists (AACC), 2000), the crude protein was calculated as N × 5.7. The protein values were adjusted to 14% moisture. Moisture was determined using Approved Method 44-19 (American Association of Cereal Chemists (AACC), 2000).

Water-soluble pentosans (WSP)

Both, the sample (100 mg) and the water (10 mL) were shaken at 30 °C for 120 min. After centrifugation, 1 mL of supernatant was mixed with the same volume of 4 N hydrochloric acid and heated at 100 °C for 120 min in a sealed tube. After cooling, an equal volume of water was added to a portion of the hydrolysed sample and 1.0 mL of the resulting mixture was analysed using the orcinol-hydrochloric acid method (Hashimoto *et al*., 1987).

Total pentosans (TP)

The sample (10 mg) was mixed with 2 mL of 2 N hydrochloric acid. The mixture was then hydrolysed at

100 °C for 150 min. After cooling, neutralisation was effected by the addition of 2 mL of 2 N sodium carbonate. Fermentable sugars were removed through fermentation where 2 mL of a 25 mg mL^{-1} of 0.2 M sodium phosphate buffer (pH 7) were added in a suspension of fresh compressed yeast (*Saccharomyces cerevisiae*) incubated for 1.5 h at 30 °C. The mixture was centrifuged at 1000 ***g*** for 10 min and an aliquot of the supernatant was analysed by the orcinol-hydrochloric acid method (Hashimoto *et al*., 1987). The content of damaged starch (DS) was determined according to Approved Method 76-30A (American Association of Cereal Chemists (AACC), 2000). A fungal enzyme from *Aspergillus oryzae* (A6211; Sigma Chemical, St Louis, MO, USA) was used.

The flour composition values were adjusted to 14% moisture. All grain and flour composition measurements were done by duplicate.

Solvent retention capacity (SRC) profile was determined by the Approved Method 56-11 (American Association of Cereal Chemists (AACC), 2000); 5 g flour samples were suspended with 25 g of water (SRC-w), 50% sucrose (SRC-suc), 5% sodium carbonate (SRC-car) and 5% lactic acid (SRC-lac). The samples were hydrated and centrifuged at 1000 ***g*** for 15 min. Each precipitate obtained was weighted and the SRC for each sample was calculated (Roccia *et al*., 2006). The analyses were carried out in duplicate.

The Rapid Visco Analyser (RVA) Series S4 A (RVA-Super 4) (Newport Scientific Pvt Ltd, Sydney, Australia) was used to determine the pasting properties of the samples. Pasting properties were determined following the 7.5 RVA Wheat and Rye Method Newport Scientific Method 5, versión 2. The RVA studies were carried out using 3.5 g of flour and 25 mL of water in an aluminium canister. The parameters recorded were peak viscosity (PV), final or cool paste viscosity (FV), breakdown (BD) and setback (SB). Flour samples were run in duplicate.

Cake baking and quality parameters

The layer cake recipe used is shown in Table 1. A single-bowl mixing procedure was used. All ingredients were mixed during 1 min at speed 3 (228 rpm) and 10 min at speed 5 (247 rpm) using a Arno mixer (Planetaria model, Sao Paulo, Brazil). 200 g of cake batter were placed into 120 mm diameter and 45 mm height, metallic, lard coated pan and baked in an electric oven for 25 min at 200 °C. The experiment was replicated, so two batters were made and five cakes were prepared from each batter.

Table 1 Cake formulation

Ingredients	Layer cake g	Layer cake %
Flour	700	27.5
Sugar	840	33.0
Milk	420	16.5
Egg	350	13.8
Sunflower oil	210	8.4
Baking powder	21	0.8

After baking, the cakes were removed from the pans and left 1 h for cooling; then cakes were sealed with plastic wraps to prevent drying. Weight, volume, symmetry, volume index, colour and texture were measured at 24 h by triplicate.

Batter density was determined as the ratio of the weight of a standard container filled with batter to that of the same container filled with water (density, 1 g cm^{-3}). Cake volume was determined by seed displacement. Symmetry and volume index were measured following the Approved Method 10-91 (American Association of Cereal Chemists (AACC), 2000) by measuring the height in different points of the cake. A digital calibre was used to measure the cake heights. Determinations were done in all cakes of each batter.

Crumb grain characteristics of cake were assessed using a digital image analysis (DIA) system. Pictures (300 dots per inch) of both sides of the cake were taken with a digital camera (Panasonic DMC-LZ7, Osaka, Japan). The analysis was performed on 34×34 mm^2 taken from the centre of a diametrical half cake. Cakes were cut using a sharp plain knife in order to minimise changes in crumb grain structure. Images were processed using Leica QWin ProV3.1 software (Leica Microsystems Imaging Solutions Ltd, Cambridge, UK). A cluster analysis method commonly known as the 'K-means algorithm' was used to obtain for each cake slice examined, an optimum gray level threshold to divide images into regions of cells and surrounding cell wall material (Sapirstein, 1999). The crumb grain characteristics studied were: mean cell area (mm^2), cell density (cells/cm^2; higher levels denote finer structure), cell to total area ratio (or void fraction, computed as the percentage of the total analysed square occupied by detected cells) and mean cell wall thickness (mm, calculated as the averaged mean intercellular distance of neighbouring cells sampled) (Sapirstein, 1999). Crumb grain parameters were measured in triplicate. Differences between cakes from the same elaboration were lower than between cakes from different elaborations verifying the analysis reproducibility.

Colour was measured using a Minolta spectrophotometer CN-508i (Minolta, Co. Ltd, Osaka, Japan). Results were expressed in the CIE $L^*a^*b^*$ colour space and were obtained using the D65 standard illuminant, and the second standard observer. Crumb texture was determined by a TA-XT2 texture analyser (Stable Microsystems, Surrey, UK) provided with the software

'Texture Expert'. A 25 mm diameter cylindrical probe was used in a 'Texture Profile Analysis' double compression test (TPA) to penetrate to 50% depth. The cross-head speed during the test was t 2 mm s^{-1} test, with 30 s delay between first and second compression. Firmness, fracturability, adhesiveness, springiness, cohesiveness, chewiness and resilience were calculated from the TPA graphic (Gómez *et al.*, 2007). Measurements were done in 20 mm thick half central slices of cakes (four measurements per cake).

Data were subjected to an analysis of variance (ANOVA) considering the cereal and the cultivar used in cake elaboration. Two set of five cakes each one were done. Duncan's test at a significance level of 0.05 was used in order to compare samples. Pearson correlation coefficients between characteristics were also calculated. Cluster analysis was performed on the basis of Euclidean distances using average linkage sorting with maximum cluster number set to three. The clusters were made using kernel and flour characteristics (PSI, protein, WSP, TP, DS, SRC and pasting parameters) as variables. Multiple linear regression was conducted with volume index as the dependent variable. Best-fit linear regression model was determined using backward variable elimination. Medium square predictive error (MSPE) was calculated as measure of predictive capacity of model to suggest volume index. All analyses were performed using the INFOSTAT statistical software (Facultad de Ciencias Agropecuarias, UNC, Argentina).

Results and discussion

Grain texture and chemical composition of rye, triticale and wheat are shown in Table 2. Rye, triticale and wheat kernels presented similar average hardness value since no significant differences in PSI values were observed. All rye cultivars showed PSI values corresponding to medium-soft, soft and very soft grain texture in agreement with Williams (1986). Wheat showed a great variability in PSI values. Two soft wheat cultivars showed the highest PSI values (TS19, TS44, very soft), and the other two lines showed the lowest (TS52, TS53, middle-hard and hard). PSI values of triticale and wheat lines were in the range of values indicated by Williams (1986).

The highest protein content corresponded to wheat flours and the lowest to rye flours. Similar values were obtained by Gellrich *et al.* (2003) when comparing rye and wheat flour proteins. A big variability was observed in protein content between different varieties of rye, triticale and wheat (from 5.75% in rye to 19.16% in wheat), in accordance with previous results (Williams, 1986; Pérez *et al.*, 2003; Roccia *et al.*, 2006). For higher protein content, higher kernel hardness measured as PSI ($r = -0.60$) were found.

Some triticale cultivars showed similar protein percentages to rye and some to soft wheat. Rye showed the highest total (TP) and water soluble pentosan (WSP) content (Table 2), however, TS 19 wheat line showed a total pentosan value higher still than rye. This wheat line have 1BL/1RS translocation that can explain the high level of total pentosan of this flour. 1BL/1RS wheat cultivars presented changes in their flour composition such as higher pentosan content (Johnson *et al.*, 1999). The wide range of WSP and TP found in wheat agree with the range of values reported by different authors (Finnie *et al.*, 2006; Dornez *et al.*, 2008). Similar content of TP and WSP in rye and triticale have been reported

Table 2 Chemical composition of rye, triticale and wheat flours

	PSI (%)	Protein (%)	WSP (%)	TP (%)	DS (%)	SRC-w (%)	SRC-suc (%)	SRC-carb (%)	SRC-lac (%)
Camilo	32.11d	5.75a	1.90a	6.41a	7.18a	146.33bc	194.74b	175.59c	152.15c
Guillermo	21.87a	10.43d	1.65a	6.46a	7.46a	101.65a	143.70a	132.60a	130.29a
Fausto	24.30b	8.13c	2.54b	6.00a	9.31b	156.11c	214.22c	181.62d	144.79bc
Lisandro	27.53c	7.07b	1.86a	5.90a	6.69a	137.18b	187.23b	161.87b	135.14ab
Rye average	26.45A	7.84A	1.99B	6.19B	7.66A	135.32B	184.97B	162.92B	140.59C
TT 1003	24.55a	13.33b	0.87b	5.04a	6.89 a	60.92a	96.43a	77.69a	69.45a
TT 1037	24.61a	9.71a	0.56a	5.15a	6.77a	65.30a	93.84a	78.79ab	74.91a
TT 1039	22.73a	11.72a	0.68ab	4.70a	6.68 a	67.54a	98.50a	85.33c	75.80a
TT 1041	17.51a	12.23ab	0.60ab	4.49a	8.37b	66.13a	107.07b	84.68bc	85.38b
Triticale average	22.35A	11.75B	0.68A	4.85AB	7.18A	64.97A	98.96A	81.62A	76.39A
TS 19	31.69c	12.05a	0.53b	7.49c	4.08a	78.79b	123.05b	95.34b	138.66b
TS 44	31.92d	13.25b	0.32a	2.01a	3.89a	57.28a	92.11a	73.90a	121.71b
TS 52	17.65b	19.16d	0.61b	3.44b	5.94b	83.20b	119.74ab	92.08b	131.29b
TS 53	15.56a	17.62c	0.53b	3.50b	10.46c	78.63b	112.72ab	91.96b	89.42a
Wheat average	24.21A	15.52C	0.50A	4.11A	6.09A	74.48A	111.91A	88.32A	120.27B

PSI, particle size index; WSP, water soluble pentosan; TP, total pentosan; DS, damaged starch; SRC-w, water SRC; SRC-suc, sucrose SRC; SRC-carb, carbonate SRC; SRC-lac, lactic SRC; SDS-SI, SDS sedimentation index. Values followed by different lower case letters within the same column and between the cultivars of the same cereal are significantly different ($P < 0.05$). Different capital letters correspond to significant difference between species averages.

by Ragaee *et al*. (2001) and Roccia *et al*. (2006). Starch damaged content did not show significant differences between cereals although the cultivars within each cereal showed a broad range (Table 2).

Solvent retention capacity (SRC) establishes a useful flour quality and functionality profile for predicting baking performance (American Association of Cereal Chemists (AACC), 2000). Water, sucrose, carbonate and lactic SRC values from rye flour were higher than triticale and soft wheat flours. The rye total content of pentosan has been reported to range from 6% to 11% (Henry, 1987; Nilsson *et al*., 2000). They are highly hydrophilic, absorbing as much as ten times their weight in water (Jelaca & Hlynka, 1971), so all SRC values from rye samples could be affected by the high pentosan content explaining the higher values obtained from this cereal.

According to the SRC profile, triticale and soft wheat flours had similar flour characteristics, particularly in pentosans and damaged starch. Roccia *et al*. (2006) also indicated that triticale showed similar sucrose SRC values than wheat, but they found higher water and sodium carbonate SRC and lower lactic acid SRC. These differences are probably related to the variability between cultivars. The rye cultivars showed the highest variability in water, sucrose and carbonate SRC values (Table 2). A clear tendency among cultivars was not observed in lactic SRC values.

In the study of pasting parameters the lowest peak viscosity of triticale was noticeable while triticale and wheat did not show significant differences between them (Table 3). Pasting properties depend on the flour composition and the enzymatic activity (Batey, 2007).

High positive correlations exist among water, sucrose, lactic and carbonate SRC values and water soluble pentosan (Table 4) showing the strong influence of this hydrophilic component in flour behaviour that can

Table 3 Peak viscosity, batter density and shape characteristics of cakes

	PV (cP)	Batter density (g cm^{-3})	Weight (g)	Volume (cm^3)	Volume index (cm)	Symmetry (cm)
Camilo	2692.5c	1.00a	178.54a	510.00a	14.20a	4.25a
Guillermo	1562.5a	1.02a	179.72a	505.00a	13.20a	4.05a
Fausto	2320.8b	1.01a	180.20a	484.59a	14.20a	4.10a
Lisandro	2597.5c	1.01a	178.12a	468.33a	13.95a	4.05a
Rye average	2293.3B	1.01A	179.14A	491.98B	13.89C	4.11A
TT1003	205.0a	0.99a	180.06ab	446.25a	12.45a	3.30a
TT1037	269.2c	1.00a	180.85b	445.84a	12.50a	2.80a
TT1039	373.3d	1.00a	179.80a	463.34a	12.55a	4.10b
TT1041	225.0b	1.01a	180.17ab	405.00a	12.25a	4.10b
Triticale average	268.1A	1.00A	180.22B	440.11A	12.44B	3.58A
TS 19	2529.0b	1.37b	181.56b	496.50b	11.15a	3.33b
TS 44	2485.1a	1.02a	179.76a	436.67a	12.65b	4.00c
TS 52	3093.3c	1.06a	181.31b	472.5ab	11.88ab	4.55d
TS 53	3058.1c	0.99a	180.46ab	465.00ab	11.85ab	2.55a
Wheat average	2791.3B	1.11A	180.77B	467.67AB	11.88A	3.61A

Values followed by different lower case letters within the same column and within each cereal are significantly different ($P < 0.05$). Different capital letters correspond to significant difference between species averages. PV, peak viscosity.

Table 4 Correlation matrix between kernel and flour characteristics

	PSI	Protein	WSP	TP	DS	SRC-w	SRC-suc	SRC-carb
Protein	−0.60*							
WSP	0.21	−0.70*						
TP	0.35	−0.64*	0.56					
DS	−0.66	−0.07	0.38	0.03				
SRC-w	0.25	−0.64*	0.94**	0.53	0.33			
SRC-suc	0.27	−0.64*	0.94**	0.54	0.31	1.00**		
SRC-carb	0.28	−0.69*	0.96**	0.56	0.32	0.99**	0.99**	
SRC-lac	0.46	−0.35	0.59*	0.37	−0.29	0.74*	0.76*	0.73*

PSI, particle size index; WSP, water soluble pentosan; TP, total pentosan; SRC-w, water SRC; SRC-suc, sucrose SRC; SRC-carb, carbonate SRC; SRC-lac, lactic SRC. *$P < 0.05$; **$P < 0.01$.

masked the specific solvent retention of other flour components. No significant correlation was observed between lactic SRC and protein percentage what corroborate previous results in soft wheat (Guttieri *et al.*, 2001) and in triticale (Roccia *et al.*, 2006). The high water soluble pentosan content of rye flours affected lactic SRC parameter producing unusual high values despite the low protein content of these flours (Tables 2 and 4), so this parameter is not suitable for protein quality estimation in rye flours. Significant correlation was neither observed between carbonate SRC and damaged starch, again the effect of soluble pentosan could be masked by the specific absorption of damaged starch.

Table 3 shows the flour peak viscosity, the density values of batter and the shape characteristics of cakes. No significant differences in batter density were observed among cereals what indicated that the quantity of incorporated air during mixing was similar. Wheat group was the most variable regard to grain texture, damaged starch, protein and total pentosan content; however no correlations were found between flour composition and batter density. Triticale and wheat cakes showed higher weight than rye. That is rye cakes lost higher water content due to evaporation, despite their high pentosans and damaged starch content (Table 2). It could be thought that the higher volume, the lower cake weight (higher water evaporation), but no significant correlation between both parameters was found. Proteins retain water preventing its evaporation. In fact, positive correlations were found between the weight and the protein content ($r = 0.65$). Rye had the highest final viscosity (data not shown). Significant positive correlation was observed between FV and SRC-w ($r = 0.65$), SRC-suc ($r = 0.65$), SRC-carb ($r = 0.61$). The highest volume and volume index belonged to rye cakes. Differences due to the cultivar were significant in wheat and rye (Table 3). Positive correlations were found between the SRC profile and the volume (SRC-w $r = 0.63$, SRC-suc $r = 0.61$, SRC-car $r = 0.64$, SRC lac $r = 0.69$) and the volume index (SRC-w $r = 0.81$, SRC-suc $r = 0.79$, SRC-car $r = 0.84$). Cake volume correlated positively with FV ($r = 0.64$). The rye arabinoxylans give higher viscosities in comparison with arabinoxylans from other cereals such as triticale and wheat (Dervilly-Pinel *et al.*, 2001). The increased viscosity of batter favours the air retention (Kim & Walker, 1992) and, in consequence, volume increases. Arabinoxylans have been shown to protect protein foams against thermal disruption (Izydorczyk & Biliaderis, 1992) and thus slow down the rate of CO_2 diffusion from dough during baking. Actually, significant correlations were found between volume and sucrose SRC ($r = 0.61$) and FV ($r = 0.64$) The correlations between volume index and WSP ($r = 0.80$, $P < 0.05$) and sucrose SRC ($r = 0.79$, $P < 0.05$) were highly significant ($P < 0.01$).

Other hydrophilic molecules as damaged starch and gluten protein can contribute to batter viscosity but only protein content showed a negative correlation with PV ($r = -0.76$). Difference in protein composition can affect the pasting behaviour (Morris *et al.*, 1997). Damaged starch did not affect significantly the viscosity parameters; however, in a previous work León *et al.* (2006) reported a decrease of peak viscosity with the increase in the damaged starch content in wheat and triticale flours. Probably the differences could be due to rye flour inclusion in the correlation analysis.

The increment in protein involved lower starch content of flour. Starch is the principal responsible of batter viscosity during heating (Morris *et al.*, 1997). Consequently the lower the protein content, the higher the viscosity. Negative correlation was observed between the volume index and the protein content ($r = -0.77$, $P < 0.05$) (Fig. S1). Sung *et al.* (2006) also observed a diminution in volume of sponge cakes when the protein content was increased. All symmetry values were positive, that means no reduction in the height of the cake centre was observed (Table 3).

Crumb image analysis did not find significant differences in mean cell area (0.35 ± 0.06 mm^2 in wheat, 0.40 ± 0.16 mm^2 in triticale and 0.32 ± 0.14 mm^2 in rye), cell density (27.78 ± 7.55 cells cm^{-2} in wheat, 26.22 ± 9.50 cells cm^{-2} in triticale and 32.05 ± 12.15 cells cm^{-2} in rye) and cell fraction area ($18.01 \pm 3.05\%$ in wheat, $18.23 \pm 5.93\%$ in triticale and $15.65 \pm 6.50\%$ in rye) among cereals. Although differences did not reach to be significant, rye cakes showed the smallest bubbles and consequently the highest density and the lowest void fraction. Significant differences were not observed due to the high typical deviations cakes obtained. The highest deviations corresponded to rye cakes indicating the least regular crumb structure. These data corroborated the visual assessment that indicated differences in the crumb appearance of rye cakes with holes and big bubbles (Fig. 1). Rye presented the thickest and wheat the thinnest wall cells (0.85 ± 0.03 and 0.78 ± 0.02 mm, respectively). In fact significant correlation ($r = 0.73$, $P < 0.05$) was found between the cell wall thickness and soluble pentosan content. Kühn & Grosch (1989) reported that the increment in arabinoxylans led to increased water requirements. Probably in our case, it would have been necessary to increase the liquid added to the formula to improve the crumb structure. Apart from the quantity, the molecular weight of arabinoxylans, the degree of arabinose substitution and the presence of other substituent influence the rheological properties and subsequently the technological functionality of rye arabinoxylans (Kamal-Eldin *et al.*, 2008). Besides, the differences between wheat, triticale and rye flour composition, as starch and protein properties, can play an important role in the crumb structure apart of

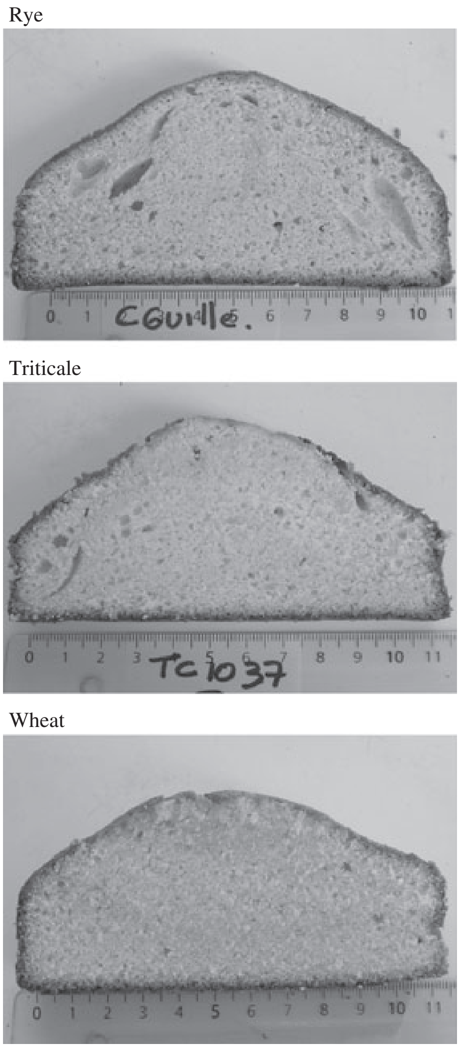

Figure 1 Photographs of rye, triticale and wheat cakes.

the level of WSP. Protein content correlated negatively with cell wall thickness (−0.64 and −0.77, respectively; $P < 0.05$) indicating that gluten proteins helped to uniform cell distribution and improved the crumb structure in agreement with Wilderjans *et al.* (2008).

Wheat cakes showed the brightest and the most reddish and yellowish crust compared to the other cereals. Triticale and rye did not significantly differ in crust colour (Table S1). Crust colour depends fundamentally on Maillard and caramelisation reactions that occur on the cake surface. Besides, differences in water content and probably in pH could affect these browning reactions. Rye and triticale have higher content of free amino acids (Shewry & Bechtel, 2001) and free sugars than wheat due to the α-amylasic activity (Ragaee & Abdel-Aal, 2006) that will favour Maillard reaction. Moreover, the higher sugars content will favour caramelisation reactions. It is expected that caramelisation reactions were less important in colour differences than Maillard reaction since the sucrose added to the formula was the same in all cases, the α-amylases do not act long time (contrary to bread), but differences in the protein content were significant (Table 2). Consequently, cakes will show darker crusts, although differences between rye and wheat did not reach significant. The observed differences in redness a^* and yellowness b^* can be related to the different quantity and quality of proteins and free aminoacid. Subagio & Morita (2008) studied the effect of protein isolate on cake characteristics and indicated that the more protein was added, the more vivid the colour. Cakes elaborated with wheat showed the highest variation in crust luminosity and yellow index. Indeed cultivar TS 44 (soft wheat) showed as low values as those from triticale and rye cutivars. No clear differences were observed in the a^* value due to the cultivar.

Rye cakes showed the darkest and the most reddish and yellowish crumb compared to the other two cereals. Inside cakes, temperatures do not reach high enough values to give Maillard and caramelisation reactions, so that crumb colour depends fundamentally on flour colour. Rye flour is more coloured attributable to the influence of coloured components in ryes such as flavonoids (Kruger *et al.*, 1998).

Cakes made with rye flour showed higher adhesiveness, cohesiveness, springiness and resilience than triticale and wheat cakes (Table S2), the firmness correlate negatively with SRC-w ($r = -0.66$, $P < 0.05$), SRC-suc ($r = -0.63$, $P < 0.05$), SRC-car ($r = -0.60$, $P < 0.05$) and volume ($r = -0.66$, $P < 0.05$) so higher hydrophilic component content decreased the crumb firmness of cakes. Stickiness has been related causally to cell-wall polysaccharides, in particular to β-glucans and pentosans (Graybosch *et al.*, 1993) and/or to the higher gliadins content (secalins in rye) (Henry *et al.*, 1989). The water-binding capacity of these components facilitate the union among ingredients and in consequence increase the work necessary to overcome the attractive forces (adhesiveness), the deformation before breaking (cohesiveness) and both retarded and instantaneous recovery capacity after stress (springiness and resilience, respectively). In fact, significant correlations were found between sucrose SRC and adhesiveness ($r = 0.84$, $P < 0.05$) (Fig. S2), springiness ($r = 0.85$, $P < 0.05$) and resilience ($r = 0.78$, $P < 0.05$).

Grain and flour characteristics (PSI, protein percentage, WSP and SRC profile) were used to group the studied cultivars through a cluster analysis. Rye cultivars formed one group (R-cluster); triticale cultivars and TS52 and TS53 (wheat cultivars) belonged to another group (TSW-cluster); and the last group was formed by the other two wheat cultivars (SW-cluster).

Table 5 Average of grain and flour parameters of three clusters

	PSI	Protein (%)	DS (%)	SRC-w (%)	SRC-suc (%)	SRC-car (%)	SRC-lac (%)	FV (cP)
R cluster	26.45ab	7.84a	7.66a	135.32b	184.97b	162.92b	140.6b	3175.7b
TSW cluster	20.44a	13.96b	7.17a	70.29a	104.72a	85.09a	87.71a	1000.33a
SW cluster	31.81b	12.65ab	5.01a	68.04a	107.58a	84.62a	130.19b	3232.5b

PSI, particle size index; WSP, water soluble pentosan; TP, total pentosan; SRC-w, water SRC; SRC-suc, sucrose SRC; SRC-carb, carbonate SRC; SRC-lac, lactic SRC; FV, final viscosity. Values followed by different letters within the same column are significantly ($P < 0.05$).

SW-cluster (TS19 and TS44) showed the lowest grain hardness and TSW-cluster the highest (Table 5). Since both SW and TSW clusters were conformed by wheat cultivars, these results indicate that wheat cultivars have the greatest variability in kernel hardness, as indicated before. TSW-cluster showed the highest protein percentage due to TS52 and TS53; which had the highest protein % from all studied cultivars. The lowest protein content still corresponded to rye cultivars (R-cluster). The SRC results were similar to the ones obtained in the cereal analysis (Tables 2 and 5) and only final viscosity showed significant differences between TSW and SW and R clusters (Table 5).

In summary, wheat and triticale cultivars showed similar flour characteristics, especially with regard to pentosans, damaged starch, but different from rye. Wheat cultivars were the most variable in relation to kernel hardness, protein content and glutenin characteristics. Wheat cultivars with the highest grain hardness and protein content were the most similar to triticale cultivars since belonged to the same cluster group.

The cluster analysis only differentiated rye cultivars (R-cluster) from the other cultivars (SW- and TSW-cultivars) in volume index, crumb L^* and a^*, adhesiveness, springiness and resilience. Grain and flour characteristics did not permit the differentiation between cake characteristics from SW- and TSW-clusters, however a higher batter density was detected for SW respect to R and TSW clusters (Table 6). Rye cakes showed the highest volume index, adhesiveness and resilience. Moreover, rye cakes had the darkest and the most reddish crumb. Crumb yellowness b^* from R-cluster cakes did not significantly differ from SW-cluster cakes. Since no significant effect was observed in crust colour, it is corroborated the idea that grain and flour characteristics are more related to crumb colour than to crust colour.

The chemical composition of flour and the predictive test used for cookie and bread quality evaluation can be used to estimate some properties of cake quality such as volume or volume index. The multiple regression analysis was used to develop an equation for cake volume index prediction using, grain texture (PSI), flour composition (protein, DS, TP and WSP), SRC and pasting parameters (PV, FV, SB and BD) as independent variables. The best-fit linear regression model was determined using backward variable elimination: Vol Index = 14.75 – 0.14 prot + 0.93 WSP – 0.27 TP. The multiple linear regression model had R^2 = 0.82 and MSPE = 0.34 (2.52% of mean volume index of rye, triticale and wheat cultivars). This result suggests that rye, triticale and wheat lines with good cake making performance can be selected on the basis of low protein and TP and higher WSP parameters.

Conclusions

Triticale flour produce as high quality cakes as soft wheat flour since no clear differences in flour and cake characteristics were obtained. The differences observed in rye flour composition were revealed in cake volume, weight, crumb colour and texture. Small deficiencies were observed in rye crumb structure that can be probably corrected with changes in the formula, in the elaboration process or in the cultivar. It is important an adequate election of the cultivar since its composition affects layer cake quality. Rye and triticale are very attractive cereals to elaborate bakery products due to their agronomic, nutritional and technological properties.

Table 6 Average of batter and cake characteristics of three clusters

	Batter density	Volume Index	L^* crumb	a^* crumb	b^* crumb	Adhesiveness	Cohesiveness	Springiness	Resilence
R cluster	1.01a	13.89b	73.74a	1.83b	24.44b	−1.06b	0.64b	0.94b	0.24b
TSW cluster	1.01a	12.25a	77.32b	0.76a	22.7a	−9.03a	0.60ab	0.87a	0.19a
SW cluster	1.19b	11.9a	79.29b	0.1a	23.78ab	−8.21a	0.57a	0.85a	0.16a

Values followed by different letters within the same column are significantly ($P < 0.05$).

Acknowledgment

This work was financially supported by Agencia Nacional de Promoción Científica y Tecnológica (ANPCyT) and CYTED project (PANXTODOS 106AC0301).

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Crust and crumb colour of rye, triticale and wheat cakes.

Table S2. Texture parameter of rye, triticale and wheat cakes.

Figure S1. Correlation between protein % and VI. Unbroken lines: regression line and 95% confidence bands. Dashed lines: 95% prediction bands.

Figure S2. Correlation between sucrose SRC and adhesiveness. Unbroken lines: regression line and 95% confidence bands. Dashed lines: 95% prediction bands.

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