

Effect of wheat flour characteristics on sponge cake quality

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Abstract

BACKGROUND: To select the flour parameters that relate strongly to cake-making performance, in this study the relationship between sponge cake quality, solvent retention capacity (SRC) profile and flour physicochemical characteristics was investigated using 38 soft wheat samples of different origins. Particle size average, protein, damaged starch, water-soluble pentosans, total pentosans, SRC and pasting properties were analysed. Sponge cake volume and crumb texture were measured to evaluate cake quality. Cluster analysis was applied to assess differences in flour quality parameters among wheat lines based on the SRC profile.

RESULTS: Cluster 1 showed significantly higher sponge cake volume and crumb softness, finer particle size and lower SRC sucrose, SRC carbonate, SRC water, damaged starch and protein content. Particle size, damaged starch, protein, thickening capacity and SRC parameters correlated negatively with sponge cake volume, while total pentosans and pasting temperature showed the opposite effect.

CONCLUSION: The negative correlations between cake volume and SRC parameters along with the cluster analysis results indicated that flours with smaller particle size, lower absorption capacity and higher pasting temperature had better cake-making performance. Some simple analyses, such as SRC, particle size distribution and pasting properties, may help to choose flours suitable for cake making.

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Keywords: wheat flour; solvent retention capacity; pasting properties; batter properties; sponge cake

INTRODUCTION

It is well known that the physicochemical characteristics of flours affect the quality of products in different ways. Knowledge is essential to take decisions in the processing industries. There are many studies concerning the influence of flour characteristics on bread quality, but few of them concentrate on the influence of those characteristics on cakes. Higher cake volume is generally associated with soft textured wheats of low protein content, which produce high break flour yield and have smaller flour particle size.¹ Nagao *et al.*² reported that kernel softness was the most important factor in the baking quality of Japanese sponge cake. Several authors have studied the relation between flour particle size and cake quality.^{1,3–5} They reported that cake volume improved as flour particle size decreased. They also pointed out that excessive pin milling increased starch damage and adversely affected cake quality. Gomez *et al.*⁶ studied the differences between mill streams and found that particle size was the most influential factor in the final volume of cakes. Meanwhile, Kahraman *et al.*⁷ found a good correlation between the parameters obtained with a Mixolab and the quality of cakes.

Generally, a sponge cake is good when the structure retains air and does not collapse, and this depends on batter viscosity and stability. The incorporation of air cells in the batter during mixing gives rise to foam. A large number of small cells provide high cake volume if the continuous phase of the batter can retain them during the baking process.⁶ The efficiency of air

retention, however, is known to be inversely proportional to bubble size.⁸ In fact, there is an optimum cake batter viscosity to achieve cakes with high volume: if the viscosity of a batter is too low, the batter cannot hold the air bubbles inside and the cake collapses in the oven; on the contrary, a batter that is too highly viscous can show restricted expansion during baking.^{8,9} Inside the oven the aerated emulsion becomes a porous semisolid, mainly owing to starch gelatinisation and protein coagulation. Both phase transitions are clearly dependent on the starch and protein sources.¹⁰ When an increase in starch gelatinisation and protein coagulation temperatures takes place, the change in the batter from a fluid, aerated emulsion to a stable, porous structure occurs later, allowing the cake to increase its volume for a longer period of time.¹¹

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The solvent retention capacity (SRC) test was developed to predict the quality of soft wheat baking products characterised by the water retention capacity of flours due to damaged starch, pentosans, gluten strength and all other constituents.^{12,13} The SRC tests measure the ability of flours to retain a set of four solvents (water and solutions of sodium carbonate, sucrose and lactic acid) after centrifugation and are widely used as indicators not only in cookie-making wheat breeding programmes^{14,15} but also in the evaluation of bread-making wheat quality.^{16,17} Generally, lactic acid SRC is associated with gluten strength, sodium carbonate SRC with levels of damaged starch, sucrose SRC with pentosan content and water SRC with all these flour constituents.^{13,18}

Batter properties are related to starch, pentosan and protein characteristics of flour,^{19–21} so the SRC can be a good estimator of cake quality. The strong correlation between SRC solvent and the main flour component^{17,22,23} suggests that this could be a useful tool to predict the quality of sponge cake by using only 5 g of flour for each SRC test. Recently, Nishio *et al.*^{24,25} found significant correlations between SRC values and sponge cake volume in non-waxy and partial waxy near-isogenic wheat lines. The SRC test has the advantage of requiring small amounts of sample, being fast and having a low cost, as it does not require expensive equipment. Utilising these tests as diagnostic tools to predict flour functionality is useful in a wheat breeding system where only small quantities of kernels are available for early generations.

In this work we studied the relationship between the SRC profile and flour physicochemical and sponge cake quality characteristics using 38 soft wheat samples of different origins and milled on different mills to select flour parameters strongly related to cake-making performance.

MATERIALS AND METHODS

Materials

Thirty-eight wheat genotypes, including advanced lines and cultivars of diverse origins, were used in this work. These genotypes included 25 soft wheats grown in Argentina and 13 bread wheats (Castilla and León landraces) grown in Spain. Argentine wheats were classified between very soft and medium hard according to particle size index (PSI) results (between 17.9 and 32.2, with an average value of 24.8). Spanish genotypes were obtained from a bank of bread wheat. Sucrose (commercial grade), milk powder and fresh whole eggs were purchased from a local market. Emulift-P (Emulift Ibérica, SL, Barcelona, Spain) was used as emulsifier.

Argentine wheats were milled on a four-roller laboratory mill (AQC 109, Agromatic AG, Laupen, Switzerland). Spanish wheats were milled on a CD1 mill (Chopin, SA, Villeneuve la Garenne, France). Flour moisture was determined using AACC method 44–19.²⁶

Flour properties

Nitrogen content was determined in duplicate by AACC method 46–13.²⁶ Crude protein was calculated as $N \times 5.7$. Protein values were adjusted to 140 g kg^{-1} moisture.

To determine water-soluble pentosans (WSP), 100 mg of sample and 10 mL of water were shaken at 30°C for 120 min. After centrifugation, 1 mL of supernatant was mixed with the same volume of 4 mol L^{-1} 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 mL of the resulting mixture was analysed using the orcinol/hydrochloric

acid method.²⁷ To determine total pentosans (TP), 10 mg of sample was mixed with 2 mL of 2 mol L^{-1} 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 mol L^{-1} sodium carbonate. Fermentable sugars were removed through fermentation, where 2 mL of a 25 mg mL^{-1} solution of 0.2 mol L^{-1} sodium phosphate buffer (pH 7) was added to a suspension of fresh compressed yeast (*Saccharomyces cerevisiae*) and incubated for 1.5 h at 30°C . The mixture was centrifuged at $1000 \times g$ for 10 min and an aliquot of the supernatant was analysed by the orcinol/hydrochloric acid method.²⁷ WSP and TP determinations were done in triplicate.

The content of damaged starch (DS) was determined in triplicate according to AACC method 76–30A.²⁶ A fungal enzyme from *Aspergillus oryzae* (A6211, Sigma Chemical, St Louis, MO, USA) was used.

The SRC profile was obtained according to AACC method 56–11.²⁶ White flour samples (5 g) were suspended with 25 g of water, 50 g kg^{-1} sucrose, 5 g kg^{-1} sodium carbonate and 5 g kg^{-1} lactic acid. The samples were hydrated for 20 min and centrifuged at $1000 \times g$ for 15 min. Each precipitate obtained was weighed and the SRC for each sample was calculated according to AACC methods.²⁶ The analyses were done in duplicate.

Particle size distribution was determined in duplicate using a Sympatec Helos laser diffraction particle size analyser (Sympatec GmbH, Clausthal-Zellerfeld, Germany) combined with a Rodos dry particle disperser (Sympatec GmbH, Clausthal-Zellerfeld, Germany).

Pasting properties of flours

The pasting viscosity of flours at 40 and 55°C was measured in duplicate using a Rapid Visco Analyser RVA-4 (Newport Scientific Pty. Limited, Warriewood, Australia) controlled by Thermocline for Windows software (Newport Scientific Pty. Limited, Warriewood, Australia) with a modified heating profile. Flour (15 g) was added to 25 mL of water in an aluminium canister. The sample was stirred at a constant speed of 160 rpm at 40°C for 3 min, with a rise in temperature to 55°C for 1 min and then 3 min at a constant temperature of 50°C . Viscosity values at 40 and 55°C were measured.

Pasting properties of flours were measured in duplicate using a Rapid Visco Analyser RVA-4 (Newport Scientific Pty. Limited) controlled by Thermocline for Windows software (AACC method 61–02²⁶). Pasting properties were determined according to the standard Newport Scientific Method 1 (STD1). The heating cycle was 50 – 95°C in 282 s, holding at 95°C for 150 s and then cooling to 50°C . Each cycle was initiated by a 10 s mix at 960 rpm paddle speed, then 160 rpm paddle speed was used for the rest of the test. The RVA studies were carried out using 3 g of sample and 25 mL of water in an aluminium canister.

Batter properties

Batter density was determined in duplicate with a measuring cylinder by means of the relation between the weight of batter and the same volume of distilled water.

Batter viscosity was measured in duplicate with a Brookfield DV-II+ viscometer (Brookfield Engineering Laboratories, Inc., Stoughton, MA, USA) using an SC4-21D spindle (Brookfield Engineering Laboratories, Inc., Stoughton, MA, USA). Samples were tempered at $28 \pm 1^\circ\text{C}$. The spindle revolved at 30 rpm. Angular velocities were chosen according to previous analyses.

Table 1. Minimum, maximum, average and standard deviation values for PSA, protein, DS, TP, WSP, SRC profile, viscosity at 40 and 55 °C and pasting parameters^{a,b,c}

| Parameter | Minimum | | Maximum | | Average | | Standard deviation | |
|--------------------------------|----------|----------|----------|----------|----------|----------|--------------------|----------|
| | Ar flour | Sp flour | Ar flour | Sp flour | Ar flour | Sp flour | Ar flour | Sp flour |
| PSA (μm) | 45.39 | 55.73 | 66.81 | 94.73 | 54.58A | 73.45B | 5.08 | 13.26 |
| Protein (g kg^{-1}) | 10.07 | 12.06 | 14.25 | 16.22 | 11.69A | 13.72B | 0.95 | 1.33 |
| DS (g kg^{-1}) | 3.46 | 4.74 | 6.22 | 9.46 | 4.68A | 6.70B | 0.66 | 1.52 |
| TP (g kg^{-1}) | 3.68 | 3.78 | 7.64 | 4.76 | 5.38B | 4.27A | 1.40 | 0.26 |
| WSP (g kg^{-1}) | 0.22 | 0.27 | 0.71 | 0.49 | 0.46A | 0.42A | 0.12 | 0.10 |
| SRCSuc (g kg^{-1}) | 88.8 | 98.8 | 115.2 | 129.7 | 98.4A | 113.8B | 6.91 | 6.76 |
| SRClac (g kg^{-1}) | 65.9 | 70.5 | 119.2 | 142.5 | 99.4A | 113.4B | 13.7 | 24.4 |
| SRCCar (g kg^{-1}) | 63.4 | 73 | 79.1 | 97.4 | 69.2A | 81.2B | 4.5 | 6.8 |
| SRCW (g kg^{-1}) | 50.7 | 55.2 | 61.8 | 78.6 | 55.7A | 63.6B | 3.2 | 6.8 |
| Thick 40 °C | 175 | 223 | 525 | 945 | 310A | 540B | 124 | 188 |
| Thick 55 °C | 193 | 186 | 491 | 864 | 303A | 518B | 104 | 181 |
| Pasting temperature (°C) | 84.8 | 67.1 | 90.6 | 87.4 | 87.8B | 78.9A | 1.4 | 8.4 |
| Peak viscosity (cP) | 1704 | 2059 | 3421 | 2644 | 2820B | 2415A | 2682 | 436 |
| Trough (cP) | 245 | 1330 | 2615 | 1858 | 2101B | 1682A | 1958 | 470 |
| Setback (cP) | 944 | 1040 | 1770 | 1510 | 1409B | 1256B | 1357 | 194 |

^a Particle size average (PSA), damaged starch (DS), total pentosans (TP), water-soluble pentosans (WSP), sucrose SRC (SRCSuc), lactic SRC (SRClac), carbonate SRC (SRCCar), water SRC (SRCW) and thickening (Thick).

^b Ar, Argentine; Sp, Spanish.

^c Values in a row followed by different letters are significantly different ($P < 0.05$).

Cake elaboration

The ingredients used were flour (245 g), egg (344 g) sugar (240.5 g), milk powder (25 g), emulsifier (14 g) and water (55 mL). A creaming mixing procedure was used. All ingredients except for the flour and milk were mixed for 2 min at speed 6 using a KitchenAid Professional mixer (KPM5, KitchenAid, St Joseph, MI, USA). After addition of the milk and flour, the mixing process was continued for 3 min at speed 8. Individual 120 mm diameter, 45 mm height, metallic, lard-coated pans were filled with 150 g of cake batter and baked in an electric oven at 200 °C for 25 min. Six cakes of each batter were baked. Two were chosen for volume analysis and two for texture analysis at random; the other two were saved for possible measurement replications.

After baking, the cakes were removed from the pans, left for 1 h at room temperature to cool and then packed hermetically in plastic bags to prevent drying. Cake quality attributes were evaluated after 24 h of storage at 25 °C.

Cake properties

Cake volume was measured in duplicate using a BVM-L370 volume analyser (TexVol Instruments, Viken, Sweden).

Crumb texture was determined using a TA-XT2 texture analyser (Stable Microsystems, Godalming, UK) equipped with Texture Expert software. A central slice of cake (20 mm thick) was laid on its side and measured for texture. A 25 mm diameter cylindrical aluminium probe was used in a texture profile analysis (TPA) double-compression test to penetrate to 50% depth at 2 mm s⁻¹ test speed, with a 30 s delay between the first and second compressions. Firmness (N), chewiness (N), cohesiveness, springiness and resilience were calculated from the TPA graph. Average results of four determinations (two central slices (20 mm thick) of two cakes per elaboration) are reported.

Statistical analysis

Results are expressed as mean of replicates \pm standard deviation. Data were subjected to analysis of variance and the results were compared by Fisher's test at a significance level of 0.05; the relationship between measured parameters was assessed by Pearson's test. Cluster analysis was performed on the basis of Euclidean distances using average linkage sorting with maximum cluster number arbitrarily set to three. The clusters were made using the four SRC solvents as variables. All analyses were performed using INFOSTAT statistical software (Facultad de Ciencias Agropecuarias, Universidad Nacional de Córdoba, Argentina).

RESULTS AND DISCUSSION

The range of values, average value and standard deviation for particle size, chemical composition, SRC parameters and pasting properties of flours are shown in Table 1. The average size of flour particles varied between 45.39 and 94.73 μm . Argentine wheats showed values significantly smaller ($P < 0.05$) than those of Spanish wheats. Particle size is affected by grain hardness, wheat type and milling method, though particle size differences observed between hard and soft wheats were much greater than differences resulting from milling methods; in addition, soft wheat milled using different milling methods did not show significant differences in particle size distribution.²⁸ Finer particle size is related to grain softness.^{22,29,30}

The mean values of protein, DS and pentosans found in Argentine wheat lines agree with those reported for soft wheat by various authors,^{15,31–34} though the ranges of DS and TP were wider. Spanish flours had significantly higher contents of protein, ash and DS and a significantly lower content of TP, whereas WSP did not differ between the two wheat groups. Differences in flour composition between wheats from Argentina and Spain could

Table 2. Correlations between PSA, protein, DS, TP, WSP, SRC profile, viscosity at 40 and 55 °C and pasting parameters^{a,b}

| | PSA | Protein | DS | TP | WSP | SRCsuc | SRClac | SRCcar | SRCw | Thick 40 °C | Thick 55 °C | Pasting T | Peak viscosity | Breakdown | Trough | Setback |
|-----------------|----------|---------|----------|--------|-------|----------|--------|----------|----------|-------------|-------------|-----------|----------------|-----------|---------|---------|
| Protein | 0.85*** | 1 | | | | | | | | | | | | | | |
| DS | 0.8*** | 0.7*** | 1 | | | | | | | | | | | | | |
| TP | NS | -0.32* | NS | 1 | | | | | | | | | | | | |
| WSP | NS | NS | NS | 0.43** | 1 | | | | | | | | | | | |
| SRCsuc | 0.67*** | 0.66*** | 0.69*** | NS | NS | 1 | | | | | | | | | | |
| SRClac | 0.45** | 0.4** | 0.4** | NS | NS | 0.42** | 1 | | | | | | | | | |
| SRCcar | 0.77*** | 0.7*** | 0.73*** | -0.38* | NS | 0.89*** | 0.34* | 1 | | | | | | | | |
| SRCw | 0.88*** | 0.76*** | 0.8*** | NS | 0.33* | 0.85*** | 0.45** | 0.88*** | 1 | | | | | | | |
| Thick 40 °C | 0.74*** | 0.69*** | 0.61*** | NS | 0.36* | 0.85*** | 0.32* | 0.77*** | 0.88*** | 1 | | | | | | |
| Thick 55 °C | 0.78*** | 0.69*** | 0.68*** | NS | 0.36* | 0.86*** | 0.37* | 0.79*** | 0.92*** | 0.96*** | 1 | | | | | |
| Pasting T | -0.84*** | -0.7*** | -0.73*** | NS | NS | -0.57*** | -0.35* | -0.75*** | -0.77*** | -0.6*** | -0.63*** | 1 | | | | |
| Peak viscosity | NS | -0.36* | -0.32* | NS | NS | NS | NS | -0.39* | -0.32* | NS | -0.32* | NS | 1 | | | |
| Breakdown | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | 0.53*** | 1 | | |
| Trough | -0.38* | -0.41** | NS | 0.35* | NS | NS | NS | -0.34* | -0.34* | NS | NS | 0.33* | 0.59*** | NS | 1 | |
| Setback | NS | -0.32* | NS | NS | NS | NS | -0.32* | NS | NS | NS | -0.33* | NS | 0.79*** | 0.4** | NS | 1 |
| Final viscosity | -0.39* | -0.45** | -0.33* | 0.36* | NS | NS | NS | -0.38* | -0.37* | -0.35* | -0.37* | 0.32* | 0.77*** | NS | 0.94*** | 0.6*** |

^a Particle size average (PSA), damaged starch (DS), total pentosans (TP), water-soluble pentosans (WSP), sucrose SRC (SRCsuc), lactic SRC (SRClac), carbonate SRC (SRCcar), water SRC (SRCw), thickening (Thick) and pasting temperature (Pasting T).

^b Significance: *** $P < 0.001$; ** $P < 0.01$; * $P < 0.05$; NS, not significant.

be due to grain properties as well as the different mills used to obtain flours. SRC values for the four solvents of Argentine wheats were significantly lower than those of Spanish wheats (Table 1). These results suggested that Spanish wheat flours presented a higher capacity to retain water. Pasting parameters of the different wheat flours were determined by RVA. Argentine wheats showed significantly higher pasting temperature, peak viscosity, trough and final viscosity (Table 1).

Correlation analysis was conducted between SRC parameters, particle size, flour components and RVA values (Table 2). Particle size average (PSA) showed significant and high correlations with protein ($r = 0.85$) and DS ($r = 0.80$). Flours with larger particle size are related to higher DS content and harder wheats, which are generally associated with high protein content.^{1,35,36} The four SRC parameters correlated positively with PSA, showing that coarser flour particles were associated with higher water absorption capacity. In relation to hard wheat, soft wheat has lower water retention capacity, finer particles and less DS.^{37,38} As expected, carbonate SRC correlated positively with DS ($r = 0.73$). These relationships have been reported in hard wheat flour by Colombo *et al.*¹⁷ and in soft wheat flour by Zhang *et al.*²² and Moiraghi *et al.*²³ High positive correlations existed between water, sucrose and carbonate SRC values and DS. No significant correlation was observed between sucrose SRC and pentosans (TP or WSP) or between lactic SRC and protein content. This could probably be explained in terms of the strong influence of DS on flour behaviour, which could mask the specific solvent retention of other flour components. No correlation between protein content and lactic SRC was previously reported in soft wheat.¹⁸ However, in hard wheat a strong correlation was observed between this parameter and protein content.^{16,17}

High and positive correlations of PSA, protein and DS with RVA viscosity at 40 and 55 °C were found. At these temperatures the gelatinisation process in starch granules did not take place and batter viscosity depended on swelling of starch granules and other flour components. Flours with more hydrophilic components such as DS, protein and arabinoxylans tend to bind more water, and the decrease in free water in the batter system increases viscosity. Free water can lubricate particles, enhance flow and result in a lower viscosity value.³⁹ Generally, viscosity has been reported to increase with increased particle size.³⁹ In order to assess cake quality, viscosity and density of the batter and volume and texture profile (firmness, cohesiveness, chewiness and gumminess) of the baked cake were determined. The range, average and standard deviation of these values are shown in Table 3. The results were similar to those observed in other studies with similar formulations.^{40,41} Sponge cakes from Argentine wheats presented lower batter viscosity, greater incorporation of air into the batter and higher volume as well as a softer texture than cakes from Spanish wheats.

Correlation analysis was conducted between SRC parameters, flour particle size, flour characteristics and cake quality parameters (Table 4). Batter density had a negative and significant correlation with cake volume ($r = -0.46$, $P < 0.01$). We can thus establish that the final volume of the cake was due to the initial air quantity in the batter. Batter viscosity is one of the factors that determine air retention. We found a high and significant correlation between batter viscosity and paste viscosity of flour measured by RVA. This could be useful as a rapid analysis to predict batter final viscosity. Batter viscosity did not present a correlation with cake volume. Although analysed separately, Argentine wheats presented a positive and significant correlation with volume ($r = 0.54$, $P < 0.01$), whereas Spanish wheats did not show any correlation. Argentine

wheats produced less viscous batters and larger sponge cakes than Spanish wheats. These results suggest that there is an optimum viscosity value to produce a positive effect on cake volume.

Sucrose, carbonate and lactic SRC presented high and positive correlations with viscosity. DS was among the chemical components of the flour that had a higher correlation with batter viscosity owing to its high capacity to retain water. DS absorbs three times more water than undamaged starch.⁴²

Volume values were between 413 and 585 cm³ (Table 3). A significant negative correlation between PSA ($r = -0.43$) and volume was found. The influence of flour particle size on sponge cake volume corroborates previous observations.^{5,41,42} Some authors related this effect to the stability produced by smaller-particle flour in the batter through the incorporation of small air bubbles.⁴⁰ A significant correlation between DS and sponge cake volume ($r = -0.37$) was observed. Howard *et al.*⁴³ demonstrated the importance of intact granular starch to cake structure. As expected, protein content correlated negatively with cake volume.^{44,45} Greater cake volume and larger cookie spread are related to soft wheats of low protein content that produce flours whose particle size is finer than that of flours produced by harder wheats during the same standardised milling process.¹ Volume did not correlate with WSP but correlated positively with TP. Arabinoxylans have been shown to protect protein foams against thermal disruption⁴⁶ and thus slow down the rate of air diffusion from dough during baking. Volume was negatively correlated with the four SRC solvents. Generally, DS and pentosans increase flour water absorption, which decreases soft wheat quality for most pastry products.⁴⁷ Lactic acid SRC may provide a useful alternative for determining protein quality. This indicates that sponge cake volume depends on the amount of protein and its quality. Cake volume cannot be explained only in terms of one flour property; rather, several factors contribute in different ways to cake volume, which explains the multiple correlations found.

Texture is an important sensory attribute in cake. Hardness is an undesirable characteristic of cake products. Cake volume correlated negatively with hardness ($r = -0.72$, $P < 0.001$), which is consistent with other studies,^{41,48} indicating that larger cakes had a soft crumb, which is a desirable property. As expected, flour components that affected cake hardness the most were protein, DS and TP owing to their influence on water retention and cake volume. Cohesiveness was the only texture parameter that was influenced by such starch pasting properties such as pasting temperature.

Another important factor for sponge cakes is the gelatinisation temperature of flour.^{49,50} Pasting temperature had a positive and significant correlation with cake volume. Starch gelatinisation at low temperatures would not allow the correct expansion of the batter. According to Kim and Walker,⁵¹ variations in cake-baking performance can be related to an optimum cake setting point by gelatinisation temperature control. Pasting temperature showed strong and negative correlations with protein ($r = -0.7$), DS ($r = -0.71$) and PSA ($r = -0.84$). Wheat flour paste viscosity determined at 40 and 55 °C showed a negative correlation with volume ($r = -0.47$ and $r = -0.48$ respectively), whereas peak viscosity did not correlate with volume. The results obtained for the 38 wheats suggest that flours with lower initial viscosity and higher pasting temperature produce more voluminous sponge cakes.

Cluster analysis was applied to assess differences in flour quality parameters among wheat lines based on the SRC

Table 3. Minimum, maximum, average and standard deviation values for sponge cake parameters of 38 wheats^{a,b}

| Parameter | Minimum | | Maximum | | Average | | Standard deviation | |
|--------------------------------------|----------|----------|----------|----------|----------|----------|--------------------|----------|
| | Ar flour | Sp flour | Ar flour | Sp flour | Ar flour | Sp flour | Ar flour | Sp flour |
| Batter viscosity (cP) | 5883 | 7500 | 9350 | 11020 | 7850A | 8790B | 1147 | 1137 |
| Batter density (g cm ⁻³) | 0.53 | 0.6 | 0.66 | 0.72 | 0.61A | 0.66B | 0.04 | 0.03 |
| Volume (cm ³) | 430 | 413 | 585 | 520 | 505B | 474A | 34 | 27 |
| Firmness (N) | 3.40 | 4.60 | 8.24 | 8.34 | 5.27A | 6.43B | 0.92 | 1.13 |
| Cohesiveness | 0.61 | 0.64 | 0.66 | 0.66 | 0.64A | 0.65B | 0.64 | 0.01 |
| Chewiness (N) | 2.00 | 2.69 | 4.51 | 5.14 | 3.04A | 3.78B | 0.51 | 0.67 |
| Gumminess (N) | 2.21 | 5.04 | 2.98 | 5.51 | 3.37A | 4.18B | 0.13 | 0.17 |

^a Ar, Argentine; Sp, Spanish.^b Values in a row followed by different letters are significantly different ($P < 0.05$).**Table 4.** Correlations between sponge cake parameters and PSA, protein, DS, TP, WSP, SRC profile, viscosity at 40 and 55 °C and pasting parameters^{a,b}

| | Batter viscosity | Batter density | Volume | Firmness | Cohesiveness | Gumminess | Chewiness |
|---------------------|------------------|----------------|---------|----------|--------------|-----------|-----------|
| PSA | 0.63*** | NS | -0.43** | NS | 0.55*** | NS | 0.35* |
| Protein | 0.45** | 0.37* | -0.4** | 0.36* | 0.6*** | 0.41** | 0.44** |
| DS | 0.54*** | 0.41** | -0.37* | 0.46** | 0.44** | 0.5*** | 0.53*** |
| TP | NS | -0.34* | 0.44** | -0.42** | NS | -0.44** | -0.44** |
| WSP | 0.47** | NS | NS | NS | NS | NS | NS |
| SRCsuc | 0.59*** | 0.46** | -0.48** | 0.44** | 0.34* | 0.47** | 0.48** |
| SRClac | NS | NS | -0.33* | NS | NS | NS | NS |
| SRCcar | 0.55*** | 0.41** | -0.46** | 0.45** | 0.42** | 0.49** | 0.51*** |
| SRCw | 0.69*** | 0.35* | -0.46** | 0.33* | 0.43** | 0.37* | 0.4** |
| Thick 40 °C | 0.68*** | 0.40* | -0.47** | 0.32* | 0.35* | 0.35* | 0.37* |
| Thick 55 °C | 0.65*** | 0.39* | -0.48** | 0.36* | NS | 0.39* | 0.41** |
| Pasting temperature | -0.41** | -0.32* | 0.43** | -0.33* | -0.49** | -0.38* | NS |
| Peak viscosity | NS | NS | NS | NS | -0.35* | NS | NS |
| Trough | -0.37* | NS | NS | NS | 0.39** | NS | NS |
| Setback | NS | NS | NS | NS | -0.33* | NS | NS |
| Final viscosity | -0.37* | NS | NS | NS | -0.44** | NS | NS |

^a Particle size average (PSA), damaged starch (DS), total pentosans (TP), water-soluble pentosans (WSP), sucrose SRC (SRCsuc), lactic SRC (SRClac), carbonate SRC (SRCcar), water SRC (SRCw) and thickening (Thick).^b Significance: *** $P < 0.001$; ** $P < 0.01$; * $P < 0.05$; NS, not significant.

profile. This analysis has been used as a powerful tool to select the best cookie-making wheat genotype based on flour characteristics.^{15,22,23} The cluster number was arbitrarily set to three. The dendrogram for the classification analysis is shown in Fig. 1. Cluster 1 was made up of 19 Argentine wheats and one Spanish wheat, in cluster 2 there were 11 Spanish and six Argentine wheats, while only one Spanish wheat sample was separated in cluster 3. Cluster 1 showed the highest cake volume, whereas wheat from cluster 3 presented the lowest cake volume (Table 5). Analysis of variance indicated that clusters 1 and 2 differed significantly in PSA, protein, damaged starch, sucrose SRC, carbonate SRC, water SRC, batter viscosity, batter density, cake volume, paste viscosity at 40 and 55 °C and pasting temperature. Pentosans, lactic SRC, texture profile of sponge cake and the other pasting parameters of flour did not show significant differences among the clusters. Cluster 1 showed the highest pasting temperature and the lowest flour particle size, protein content, DS content, SRC values and paste viscosity at 40 and 55 °C. The cluster analysis further established the usefulness of SRC

for selecting desirable genotypes of good sponge cake-making quality in breeding programmes.

CONCLUSION

Through SRC analysis it was possible to identify wheats in three clusters with different flour characteristics and cake-making performance. Cluster analysis and Pearson's correlation indicated that flours with smaller particle size, lower water retention capacity and higher pasting temperature had better cake-making performance. Damaged starch and protein quantity play a negative role in sponge cake quality, pentosans improve it, while protein quality did not seem to affect it.

The results presented here demonstrate that it is difficult to obtain enough information from a single assay to define whether a flour is suitable for cake making or not, as in the case of fermented baking products, where, for example, an alveograph or farinograph may help to determine if a type of flour is appropriate for breadmaking. However, some simple analyses such as SRC,

Table 5. Cluster analysis of 38 wheat lines based on SRC profile^{a,b}

| Cluster | Protein (g kg ⁻¹) | PSA (μm) | DS (g kg ⁻¹) | SRCsuc (g kg ⁻¹) | SRCcar (g kg ⁻¹) | SRCw (g kg ⁻¹) | Volume (cm ³) | Batter viscosity (cP) | Batter density (g cm ⁻³) | Firmness (N) | Gumminess (N) | Chewiness (N) | Thick 40 °C | Thick 55 °C | Pasting T (°C) |
|------------------------|----------------------------------|-------------|-----------------------------|---------------------------------|---------------------------------|-------------------------------|------------------------------|--------------------------|---|-----------------|------------------|------------------|----------------|----------------|-------------------|
| Cluster 1 ^c | 11.65a | 53.78a | 4.63a | 95.3a | 67.7a | 54.3a | 508c | 7620a | 0.61a | 5.2a | 3.34a | 3.0a | 253a | 254a | 87.4c |
| Cluster 2 ^d | 13.13b | 65.79b | 6.12b | 112.0b | 78.6b | 62.0b | 483b | 8652b | 0.65b | 5.7ab | 3.72ab | 3.4ab | 515b | 492b | 82.7b |
| Cluster 3 ^e | 15.30b | 94.73c | 7.63a | 129.7c | 97.4c | 78.6c | 413a | 11020c | 0.62ab | 6.2b | 4.00b | 3.6b | 945c | 864c | 66.2a |

^a Particle size average (PSA), damaged starch (DS), sucrose SRC (SRCsuc), carbonate SRC (SRCcar), water SRC (SRCw), thickening (Thick) and pasting temperature (Pasting T).

^b Mean quality parameters of each cluster by analysis of variance. Values in a column followed by different letters are significantly different ($P < 0.05$).

^c Lines 3, 9, 11, 13, 14, 18, 19, 21, 24, 34, 36, 38, 39, 42, 43, 44, 48, 49, 50 and ZT-267.

^d Lines 8, 20, 25, 31, 33, 37, Barbilla, BGE000084, BGE12575, BGE13129, BGE18228, BGE30460, BGE30462, ZT-262, ZT-263 and ZT-266.

^e Line BGE-12144.

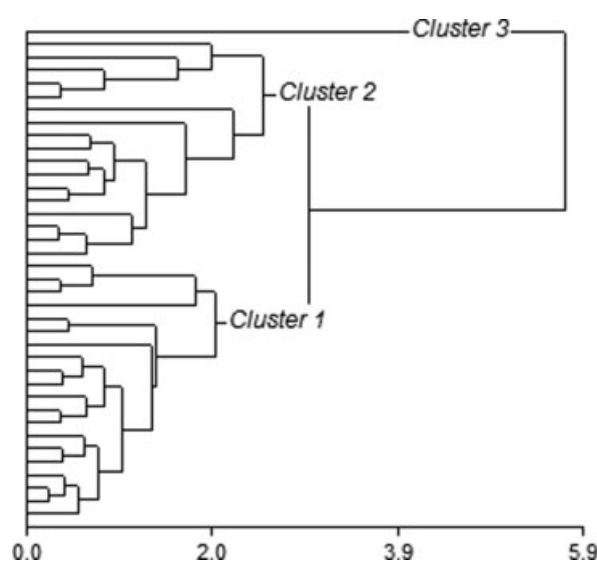


Figure 1. Dendrogram from classification of cultivars by Ward's method using SRC profile as variable: cluster 1, $n = 20$; cluster 2, $n = 17$; cluster 3, $n = 1$.

particle size distribution and pasting properties of flour may help to characterise the types of flour suitable for cake making.

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