# MAIZE BASED GLUTEN FREE BREAD: INFLUENCE OF PROCESSING PARAMETERS ON SENSORY AND INSTRUMENTAL QUALITY

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**Abstract**

The performance of maize bread with spongy texture is still a technological challenge due to the absence of a natural network required for holding the carbon dioxide released during the fermentation process. The objective of this research was to investigate the influence of different maize varieties (regional and hybrid), milling process (electric and water mill), formulation and processing variables on the sensory and instrumental (specific volume, texture and colour) quality attributes of corn bread. For that purpose, the traditional breadmaking process applied to the development of the ethnic Portuguese bread (*broa*) obtained from composite maize-rye-wheat flour was modified to produce gluten-free *broa*. Significant differences ($p<0.05$) between regional and hybrid maize were detected in terms of protein, amylose, and maximum, minimum and final viscosities as evaluated by Rapid Visco Analyser. Concerning the effect of milling process, the grinding in a water mill occurs at slower rate than it does in the electrical mill, in consequence the flour from water milling had lower ash content and higher maximum, minimum and final viscosities than the one obtained from electrical milling. An important point in the breadmaking process was the flour blanching that resulted in doughs with higher consistency, adhesiveness, springiness and stickiness as measured by texture analyser, due to the partial gelatinization of the corn starch. Baking assays demonstrated that broa breadmaking technology could be satisfactorily applied to produce gluten-free *broa* with acceptable quality characteristics better than bread made from regional maize varieties.

Keywords: maize flours, blanching, rheology, *broa*, maize bread, gluten free bread

## 1. Introduction

Wheat proteins have the unique properties of developing a viscoelastic matrix when wheat flour is mechanically mixed with water. This viscoelastic network enables the dough to hold the gas produced during the fermentation process, leading to an aerated crumb bread structure. Unfortunately, gluten must be kept apart from the diet of celiac patients, who suffer very important intestinal damage when they ingest gluten containing products. This technological obstacle has been overcome by using complex bread recipes with different starches and cereal flours like corn starch, brown rice, soy and buckwheat flour (Gallagher et al., 2004; Moore et al., 2006), or a composite blend of rice flour with corn and cassava starches obtaining gluten-free bread with a well structured crumb and pleasant flavour and appearance (Sanchez et al., 2002; Lopez et al., 2004). Generally, in the performance of gluten free bread, a variety of hydrocolloids or gums have been used for creating a polymer network with similar functionality than the wheat gluten proteins. In fact, gluten free breads have been successfully developed using several combinations of cellulose derivatives (Gujral & Rosell, 2004a, Schober et al., 2007). With the same purpose, crosslinking enzymes (glucose oxidase and transglutaminase) have been used as processing aids for improving rice based gluten free bread quality (Gujral and Rosell, 2004a,b; Moore et al., 2006). Lately, different proteins have been proposed as alternative for both playing the polymer role and increasing the nutritional value of gluten free products (Marco & Rosell, 2008a, b, c).

It is clear that the common player when gluten free breads are developed is the presence of a polymer with certain viscoelasticity and ability to entrap the other components of the system; and usually they are incorporated as ingredients of the recipe. Nevertheless, an attractive alternative would be to perform gluten free breads by using only gluten free cereals and to generate 'in situ' during the breadmaking process the required holding biopolymer.

*Broa* is Portuguese ethnic bread made with more than fifty per cent of maize mixed with wheat or rye flours, highly consumed in the north and central zones of Portugal (Brites et al., 2007a). Bread making process is mainly empirical and several types of *broa* are produced depending on maize types and blending flours, although local maize landraces are usually prefered (Vaz Patto et al., 2007). Maize flour for breadmaking was traditionally obtained in stone wheel mills, moved by water or wind, and nowadays frequently by electricity. There are many recipes to prepare *broa,* but the traditional process (Lino et al., 2007) involves adding maize flour (sieved whole meal flour), hot water, wheat flour, yeast and leavened dough from the late *broa* (acting as sourdough). After mixing, resting and proofing, the dough is baked in a wood-fired oven. This empirical process leads to an ethnic product highly accepted for its distinctive sensory characteristics. Nevertheless scarce scientific studies on *broa* breadmaking have been reported, and research have been focused on the partial replacement of wheat flour by maize flour (Martínez & el-Dahs, 1993) or maize starch (Miyazaki & Morita, 2005) or developing formulations based on maize starch (Sanni et al., 1998; Özboy, 2002).

Maize is a gluten free cereal, thus suitable to produce foods addressed to celiac patients. The acquired knowledge on *broa* (made from composite maize-rye-wheat flour) is important for facing the challenges in producing gluten-free bread that usually exhibits compact crumb texture and low specific volume (Rosell & Collar, 2007; Rosell & Marco, 2008). Therefore, a better understanding of this breadmaking process would provide the basis for developing gluten free bread based on maize flour.

The objective of this study was to assess the impact of different factors as maize variety, type of milling, water mixing temperature on maize dough rheology and to define and optimize the maize breadmaking and to identify their effect on specific volume, texture and sensory quality of the maize bread performed by applying the technology of *broa.*

## 2. Material and Methods

### 2.1. Maize flours characteristics

Four maize varieties selected based on genetic background (Moreira, 2006) were used in this study (Table 1). Whole meal maize flour was obtained after milling the selected varieties in artisan water-mill and electric-mill (model M-50, Agrovil, Portugal), both having millstones. Whole meal flour was sieved through 0.5mm screen, and larger particles were discarded to obtain maize flour.

Flour protein and ash content were determined in triplicate following ICC standard 105/2:1994 and 104/1:1990 methods. Apparent amylose content was determined following the ISO 6647-2:2007 using 720nm as wavelength, and a calibration curve previously performed with maize flour samples according to ISO 6647-1:2007.

Viscosity profiles were obtained with a Rapid Viscosity Analyser (RVA, Newport Scientific, Australia), according to Almeida-Dominguez et al. (1997) at 15% solids, using the following time (min): temperature (ºC) settings 0:50, 2:50, 6.5:95, 11:95, 15:50, 25:50, the time (min):speed (rpm) programme were 0:960, 10:160. Maximum, minimum (or trough) and final viscosities (cP units) were recorded and the breakdown calculated as maximum viscosity-minimum viscosity.

Maize flour colour was determined on 10-12g of sample in an opaque recipient by using a Minolta Chromameter CR-2b. Maize flour tristimulus colour parameters included: L* - lightness, a* - red/green index, b* - yellow/blue index and ΔE – colour total variation relative to a white surface reference ($L^*=97.5$ $a^*=-0.13$ $b^*=1.63$). Values are the mean of 10 replicates.

## 2.2. Dough rheological properties

Dough rheological properties were evaluated in a conventional Brabender farinograph® (Duisburg, Germany) following the method ISO 5530-1:1997 with some modifications. Maize flour (40g) were mixed in the Farinograph 50g bowl with 44mL of distilled water (110% flour basis) during 20min. Assays were carried out under two different conditions, at 25ºC and by adding boiling water (100ºC). The parameters obtained from the farinogram included Td (development time in minutes, time to reach the maximum consistency), the dough consistency at the Td ($C_{Td}$) and the consistency after 20min mixing ($C_{20}$), both in BU (Brabender Units).

Mechanical and surface related properties were determined in the resulting dough, either from 25ºC and 100ºC. Dough machinability was determined by assessing the texture profile analysis (TPA) and dough stickiness in a TA-XT2i texturometer (Stable Micro Systems, Godalming, UK) as described by Armero & Collar (1997) using the Chen & Hoseney cell. Primary textural properties were measured in absence of dough adhesiveness by using a plastic film on the dough surface to avoid the distortion induced by the negative peak of adhesiveness (Collar & Bollaín, 2005). The adhesiveness was measured without the plastic film. Three and ten repetitions for the TPA parameters and stickiness were done, respectively. Compression test was performed with a 50mm of diameter cylindrical aluminium probe, a 60% compression rate followed of 75s interval. TPA profile recorded the following parameters: hardness (g/force), adhesiveness (g/s), cohesiveness and springiness. For dough stickiness (g/force) determination was used the

Chen & Hoseney cell with a cylindrical probe of 25mm diameter (Armero & Collar, 1997).

### 2.3. Breadmaking process

The traditional *broa* formulation included 70 % of maize flour, 20 % of commercial rye flour (Concordia type 70, Portugal), 10 % of commercial wheat flour (National type 65, Portugal), 95 % (v/w, flour basis) of water, 3.6 % (w/w, flour basis) sugar, 2.2 % (w/w, flour basis) salt, 0.5 % (w/w, flour basis) of improver (S500 Acti-plus, Puratos) and 0.8 % (w/w, flour basis) dry yeast (Fermipan, DSM, Holland). Sourdough was prepared using the same recipe of *broa* and adding enough bacteria suspension (*Lactobacillus brevis* and *plantarum* previously isolated) to yield $10^7$ CFU (colony formed units)/g mass concentration. Sourdough was kept at 25ºC during 12h before its use. Traditional *broa* baking trials were performed with the four maize varieties milled with two different mills, which gave a total of eight different maize flours (n=8).

Breadmaking process consisted in mixing the maize flour with 77% (v/w, flour basis) boiling water containing 2.2% salt, for 5 minutes in the bowl of Kenwood kitchen Machine. Dough was left idle till cooling to 27°C, then the remaining ingredients (including 18 % water containing 2.2 % salt and 10 % w/w flour basis of sourdough) were added and dough was kneaded again for 8 min and left resting for bulk fermentation at 25ºC for 90min. After fermentation, the dough was manually moulded in balls of 400g and baked in the oven (Matador, Werner & Pfleiderer Lebensmitteltechnik GmbH) at 270ºC for 40min. For each trial, three samples were produced and analysed separately.

An adapted breadmaking process was carried out for obtaining gluten free maize bread, in which rye and wheat flours were replaced by maize flour and recipe contained 110 % (v/w, flour basis) of water, identical proportion of the other traditional *broa* ingredients (sugar, salt, improver, dry yeast). Gluten free baking trials were performed with *Pigarro* and *Fandango* maize varieties milled in artisan water mills (n=2).

## 2.4. Bread analyses

Quality technological parameters of breads were determined the following day to its production. Quality parameters included: weight (g), volume ($cm^3$) using polyethylene spheres displacement method (Esteller & Lannes, 2005). Specific volume was then calculated in $cm^3/g$.

The tristimulus colour parameters (L*, a*, and b*) of crumbs were determined using Minolta Chromameter Model CR-2b colorimeter.

Bread slices (25mm thickness) were used for crumb firmness determination through compression test in a texture analyser (TA-Hdi, Stable Micro Systems, Godalming, UK) using adapted American Institute of Baking- AIB Standard Procedure (2007): 12.5mm cylindrical probe, 2.0mm/s test speed, 10g trigger force, 6.2cm compression distance after detecting resistance (crumb surface) and final speed test of 10mm/s. Firmness in g-force was automatically recorded by the data processing software.

Sensory analysis (ISO 8587, 1988) was conducted with a panel of twelve trained judges that quantify the influence of different maize varieties on overall differentiation of *broa* and maize bread. Triangular assays (AACC 33-50A, 1999) were carried out for each maize variety subjected to the two types of milling. Paired comparison tests (ISO 5495, 1983) were conducted to compare different varieties (within each colour group- white or yellow), panelists were asked to ranking the samples based on overall texture, taste and aroma. Traditional *broa* was compared with gluten free maize bread.

## 2.5 Statistical analysis

The effect of different flour (maize variety, type of milling) and dough (water mixing temperature) variables on respectively flour chemical composition, colour, viscosity profile, dough rheological and bread technological quality parameters were analysed by analysis of variance (ANOVA). Means comparisons were performed by Duncan's test also used for compared traditional *broa* with gluten free maize bread. Significant correlations between flour composition, viscosities and dough rheological parameters were determined with Pearson correlations analysis. All statistical analyses were conducted at a significant level of $P \leq 0.05$ with Statistical Analysis System (SAS Institute, Cary, NC, 1999).

## 3. Results and discussion

### 3.1. Effects of maize varieties and milling types on flour composition, colour and viscosities

The viscosity profile of a wide germplasm collection of pure lines, hybrids and local maize populations was previously characterized by Santos (2006) and four varieties (*Pigarro, Fandango*, Yellow Hibrid and White Hibrid) (Table 1) were selected for bread production with and without composite rye-wheat flours. The effect of milling type on the flour and dough characteristics was also studied to assess the possible influence of the new practices (electrical mill) compared to the traditional ones (stone mill).

Significant differences between maize varieties were detected for protein and amylose contents ($P < 0.05$) (Table 2). Regional varieties (*Fandango*, *Pigarro*) exhibited significant higher protein content and lower amylose content than hybrids. *Pigarro* flour had the highest ash content probably due to its endosperm of flint type. Type of milling influenced significantly ($P<0.05$) the ash content that affects pH profile during fermentation and, in turn, will influence bread quality. The type of grinding did not have any influence on protein and amylose content.

As expected, type of variety showed greater significance ($P<0.05$) on flour colour parameters than milling type (Table 3). Despite of testing two yellow maize (*Fandango*, Yellow Hibrid) and two white maize (*Pigarro*, White Hibrid), there were significant differences ($P< 0.05$) concerning a* and b* parameters between the yellow varieties and only significant differences in a* values between the white varieties. The type of milling affected significantly ($P<0.05$) the lightness (L) of the maize flours (data not shown).

Viscosity profile of four maize flours during a heating-cooling cycle was recorded by using the rapid viscoanalyzer (RVA) (Figure 1). Compared with commercial wheat flour (results not shown) maize flour exhibited lower pasting temperature, lower maximum viscosity and higher final viscosity, therefore higher setback was obtained. Similar results were obtained by Martínez & el-Dahs (1993), who detected a reduction of the maximum viscosity and an increase in the final viscosities of the wheat flour when adding instant maize flour (up to 25%). When compared the viscosity profile of the different maize varieties, maximum and final viscosities values from hybrid varieties were significantly ($P<0.05$) higher than those of the regional ones (*Fandango*, *Pigarro*) (Table 4). Flint maize varieties have harder endosperm than the dent varieties and their flours have distinct viscosity profile (Brites et al., 2007a,b). *Fandango* maize flour variety (regional dent type) presented superior values than *Pigarro* (regional flint type), agreeing to previously data (Santos, 2006; Brites, 2006). Previous findings reported that the flint maize shows lower maximum viscosity and lower setback than dent varieties (Almeida-Domingués et al., 1997; Sandhu et al., 2007; Brites et al., 2007b).

The milling type variation influenced maximum viscosity (Table 4) and also breakdown, being the average values of the flour from water mill higher and significantly different than the results of flour from the electric mill. The electric milling process yielded flour with lower viscosity profile likely associated to the negative impact of damage starch on the ability to absorb water.

**3.2. Effects of maize varieties, milling type and water temperature on dough farinograph and texture parameters**

The behaviour of the dough during mixing and handling was analysed by using the Farinograph and texturometer respectively, considering the effect of the variety and milling type as well as the mixing water temperature. No influence of variety and milling type was detected (Table 5) on those parameters, with exception of the significant ($P<0.05$) effects of the milling process on dough hardness.

The temperature of the added water for making the dough was the major factor of variability (Table 6). Water temperature significantly ($P<0.05$) affected development time (Td), the consistency of the dough ($C_{Td}$) and the stability of the dough (related to the consistency after 20 min mixing). Concerning dough machinability, the temperature of the dough did not significantly affect hardness, but resulted in a significant ($P<0.05$) effect on adhesiveness, gumminess and stickiness of the dough. When boiling water was used for dough mixing, maize dough showed significantly ($P<0.05$) higher consistencies with minor development times compared to doughs mixed at 25ºC dough. Associated with the increase of the water temperature was the increase of mechanical and surface related parameters adhesiveness, elasticity, and stickiness and subsequent reduction of cohesiveness. These results were not unexpected since previous studies reported that dough rheological parameters were particularly affected by starch gelatinisation (Miyazaki & Morita, 2005). The addition of boiling water to the maize flour promoted the partial gelatinization of the starch, increasing the viscosity of the dough, consequently, leading to higher dough consistency. The gelatinization occurs as the temperature rises, which increases mechanical strength of dough. This is an important factor to consider when maize flours are destined to gluten free breadmaking obtaining a viscous system that holds the components of the system. In fact, Rosell & Marco (2007) observed a decrease in the peak of maximum viscosity after heating rice flour dough prepared by using heated water during mixing, due to the previous partial gelatinization when warm water was added. Similar effects have been observed when the pasting characteristics of native and heat-moisture treated maize starches were compared (Hoover & Manuel, 1996). As a consequence of the initial starch gelatinization, dough consistency increases, improving the mechanical and handling properties of the rice flour dough compared to those of the dough mixed with water at 25°C (Marco & Rosell, 2008a)

Therefore, an alternative for improving gluten-free dough consistency is to promote the partial starch gelatinisation through the addition of boiling water when mixing. Relationships between flour composition and viscosity and dough rheological parameters were particularly significant for dough textural parameters *vs* flour parameters. Significant correlations ($P<0.05$) between amylose and cohesiveness were detected ($r=0.72$), whereas springiness and stickiness parameters were associated to gelatinization and retrogradation phenomena ($r>0.71$), as were previously found for wheat doughs (Collar & Bollaín 2005; Collar et al., 2007).

**3.3. Effect of maize varieties and milling types on bread specific volume, colour, firmness and sensory assessment**

A preliminary breadmaking study was performed varying the temperature (25°C or 100°C) of the water added to the maize flour during mixing, *broa* obtained by adding water at 100°C showed superior crumb texture quality than the ones obtained at 25ºC water temperature (results not showed). Further breadmaking trials were made following the traditional *broa* making procedure, using boiled water for mixing maize flour.

Traditional ethnic bread, *Broa*, was made for defining breadmaking conditions prior to the performance of gluten free maize bread because although does The specific volume of the *broa* ranged from 1.40 to 1.57cm$^3$/g (Table 7), which could be considered low values if compared with wheat bread loaves. Traditionally, *Broa* is a type of bread with high density and closed crumb cells, thus high specific volume is not desirable. Besides breads made or containing high amounts of gluten free cereals show low specific volume compared to the ones obtained with wheat flour (Marco & Rosell, 2008a).

Regarding the effect of maize varieties and milling type on the specific volume of *broa*, no significant differences were detected (Table 7). Significant differences ($P<0.05$) were induced by maize varieties in the colour parameters and firmness, by contrast no significant differences (exception to blue/yellow parameter -b*) were obtained between flours obtained from water and electric mills. Maize varieties had a significant effect on the firmness of the bread crumb, being the crumbs from *Pigarro* maize variety significantly harder than the ones from *Fandango*.

Sensory triangular assays of *broa* showed no significant differences ascribed to the type of mill (data not shown). Sensory rank sums and paired comparison test of regional and hybrid maize varieties within each colour (white or yellow type) showed the preference of regional maize varieties in detriment of hybrids (22.0 vs 14.0 in the case of yellow types and 20.0 vs 16.0 in the case of white types). The judges defined *Fandango* variety *broa* with better characteristics of mouth feel flavour and texture, even though *broas* produced with the hybrid varieties had higher specific volume.

From the above results, *Fandango* and *Pigarro* varieties were selected for performing gluten free maize bread, since they were the preferred varieties by the judges. The study was restricted to the maize flours from water mill, because milling type did not induce significant differences on the *broa* quality. The specific volume of gluten free maize bread ranged from 1.02 to 1.12 $cm^3/g$. As expected the gluten free breads presented from 20 to 30% less specific volume than their counterparts produced with the traditional recipe (obtained from composite maize-rye-wheat flour). Sanni *et al* (1998) obtained maize bread containing egg proteins with 0.95 $cm^3/g$ specific volume. Similar bread specific volume had been reported in rice based breads, which were improved by using crosslinking enxymes (Gujral & Rosell, 2004 a,b), hydrocolloids (Marco *et al*, 2007) or proteins (Marco & Rosell, 2008 a).

Gluten free maize bread displayed smaller volume with slightly more compact structure than the traditional *broa*, which showed defined gas cells in the crumb (Figure 2). Gluten free breads due to the absence of a protein network cannot retain the carbon dioxide produced during the fermentation, leading to a product with low specific volume and compact crumb (Rosell & Marco, 2008), which has a close appearance resemblance to the Portuguese ethnic bread.

A comparison was made between the quality parameters of the *broa* and the gluten free bread. Significant differences were detected in the colour and texture parameters between gluten free and traditional *broa*. As was expected, crumb firmness of gluten free bread was significantly higher (+ 50%) than the one obtained in the traditional *broa*, which agree with the specific volume results obtained. Reduced loaf volume and firmer crumb texture of gluten free bread when compared with traditional *broa* was attributed to maize gluten absence, as has been previously observed in other gluten free bread recipes (Rosell & Marco, 2008).

Sensory ordinance test showed contradictory results depending on the maize variety used for breadmaking. Significant differences ($P<0.05$) between gluten free and traditional *broa* obtained from *Pigarro* maize flour were obtained in the sensory paired preference test, the sensory panel preferred traditional *broa* (22.0 vs 14.0). Conversely, in the case of *Fandango* (yellow variety), no significant differences ($P<0.05$) were observed between the scores that received the traditional *broa* and the gluten free maize bread. *Fandango* variety was sweeter than *Pigarro* and it seems to perform better in breadmaking process that includes sourdoughs.

## 4. Conclusions

Breads were obtained from maize and composite maize-rye-wheat flour, studying the effect of maize varieties, milling process, and processing variables on the dough characteristics and bread quality. Significant differences between regional and hybrid maize were detected regarding protein, amylose and RVA viscosity profiles. Concerning the effect of milling process, the grinding in a water mill occurs at slower rate than in the electrical, obtaining flour with lower ash content and higher viscosities. Nevertheless the influence of milling type on flour parameters, no significant differences were detected in *broa* sensory triangular tests and ordinance tests had neglected hybrid maize in relation to the regional ones.

Baking assays demonstrated that *broa* breadmaking technology could be satisfactorily applied to produce gluten free *broa.* An important point in the breadmaking process was the blanching that resulted in doughs with higher consistency, because in the absence or reduced amount of gluten the dough rheological properties are provided by the starch gelatinisation. Maize based gluten free bread were obtained following *broa* breadmaking process, obtaining bread with satisfactory sensory characteristics and similar appearance than the traditional *broa.*

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**Table 1** – Characteristics of maize varieties used in this study.

| Variety | Type | Endosperm | Color |
|---|---|---|---|
| *Pigarro* | Regional, local germplasm, open pollinated | Flint | White |
| *Fandango* | Regional, exotic germplasm, open pollinated | Dent | Yellow |
| Yellow Hybrid | Hybrid | Dent | Yellow |
| White Hybrid | Hybrid | Dent | White |

**Table 2 –** Effects of maize variety and milling type on protein, ash and amylose contents of maize flours

| Factor | Level | Protein (% db) | Ash (% db) | Amylose (% db) |
|---|---|---|---|---|
| Variety | *Fandango* | $9.5^{b}$ | $1.50^{b}$ | $28.6^{b}$ |
| | *Pigarro* | $10.5^{a}$ | $1.94^{a}$ | $29.2^{b}$ |
| | Yellow Hybrid | $8.3^{d}$ | $1.49^{b}$ | $32.7^{a}$ |
| | White Hybrid | $8.8^{c}$ | $1.39^{b}$ | $32.3^{a}$ |
| Milling type | Water mill | $9.31^{a}$ | $1.48^{b}$ | $31.10^{a}$ |
| | Electric mill | $9.27^{a}$ | $1.68^{a}$ | $30.29^{a}$ |

For each parameter and single factor, values followed by the same letter are not significantly different at $p<0.05$.

**Table 3** – Effect of maize variety on colour parameters.

| **Variety** | **L*** | **a*** | **b*** |
|---|---|---|---|
| *Fandango* | 87$^{b}$ | -1.49$^{c}$ | 38.7$^{a}$ |
| *Pigarro* | 89$^{b}$ | -0.04$^{a}$ | 12.6$^{c}$ |
| Yellow hibrid | 88$^{b}$ | -1.86$^{d}$ | 33.7$^{b}$ |
| White hibrid | 92$^{a}$ | -0.07$^{b}$ | 10.5$^{c}$ |

For each parameter, values followed by the same letter are not significantly different ($p$<0.05).

**Table 4** – Effects of maize variety and milling process on RVA parameters (maximum, minimum and final viscosities and breakdown) of flour.

| Factor | Level | Maximum Viscosity (cP) | Minimum Viscosity (cP) | Final Viscosity (cP) | Breakdown (cP) |
|---|---|---|---|---|---|
| Varieties | *Fandango* | $2999^{b}$ | $1391^{c}$ | $4675^{b}$ | $1609^{b}$ |
| | *Pigarro* | $1580^{c}$ | $1088^{d}$ | $3168^{c}$ | $492^{c}$ |
| | Yellow Hybrid | $5342^{a}$ | $2004^{b}$ | $6344^{a}$ | $3338^{a}$ |
| | White Hybrid | $5484^{a}$ | $2340^{a}$ | $6745^{a}$ | $3144^{a}$ |
| Milling Type | Water mill | $4140^{a}$ | $1764^{a}$ | $5387^{a}$ | $2376^{a}$ |
| | Electric mill | $3562^{b}$ | $1647^{a}$ | $5078^{a}$ | $1915^{b}$ |

For each parameter and single factor, values followed by the same letter are not significantly different at $p<0.05$.

**Table 5-** Farinograph and texturometer dough mean parameters from four maize varieties, two types of milling and two mixing temperatures.

| **Variety** | **Milling type** | **Water temperature (ºC)** | **Td (min.)** | **$C_{Td}$ (BU)** | **$C_{20}$ (BU)** | **Hardness (g/force)** | **Adhesiveness (g/s)** | **Gumminess** | **Stickiness (g/force)** |
|---|---|---|---|---|---|---|---|---|---|
| *Fandango* | Water | 25 | 13.0 | 55 | 60 | 2502 | 1016 | 300 | 16.1 |
| | | 100 | 6.5 | 95 | 80 | 2058 | 2211 | 121 | 21.4 |
| | Electric | 25 | 6.5 | 80 | 90 | 2661 | 2831 | 286 | 20.9 |
| | | 100 | 4.0 | 210 | 145 | 2824 | 12758 | 223 | 25.2 |
| *Pigarro* | Water | 25 | 7.5 | 60 | 65 | 4179 | 1341 | 260 | 16.1 |
| | | 100 | 8.8 | 260 | 260 | 6500 | 5867 | 735 | 20.2 |
| | Electric | 25 | 10.0 | 75 | 75 | 2131 | 1098 | 201 | 19.1 |
| | | 100 | 3.5 | 120 | 195 | 2258 | 4137 | 137 | 25.3 |
| Yellow hibrid | Water | 25 | 10.0 | 75 | 80 | 2948 | 2244 | 353 | 21.0 |
| | | 100 | 7.5 | 185 | 165 | 2876 | 11458 | 241 | 26.2 |
| | Electric | 25 | 6.5 | 80 | 80 | 2012 | 3529 | 178 | 20.5 |
| | | 100 | 6.8 | 150 | 140 | 2541 | 5348 | 203 | 29.0 |
| White hibrid | Water | 25 | 14.5 | 90 | 100 | 3825 | 4297 | 464 | 17.0 |
| | | 100 | 5.0 | 150 | 160 | 3008 | 7514 | 288 | 30.3 |
| | Electric | 25 | 7.5 | 50 | 55 | 2078 | 1785 | 270 | 16.9 |
| | | 100 | 7.8 | 100 | 90 | 2256 | 4980 | 176 | 24.7 |

Td – development time (min), $C_{Td}$ – consistency at development time, $C_{20}$ – consistency at 20min

**Table 6 –** Effect of water temperature on dough Farinograph and texturometer parameters.

| | Water temperature | |
|---|---|---|
| | **25ºC** | **100ºC** |
| Td (min) | $9.4^{a}$ | $6.2^{b}$ |
| $C_{Td}$ (UB) | $71^{b}$ | $159^{a}$ |
| $C_{20}$ (UB) | $76^{b}$ | $154^{a}$ |
| Adhesiveness (g/s) | $2267^{b}$ | $6784^{a}$ |
| Cohesiveness | $0.11^{a}$ | $0.08^{b}$ |
| Springiness | $0.25^{b}$ | $3.2^{a}$ |
| Stickiness (g/force) | $18.5^{b}$ | $25.3^{a}$ |

Td – development time, $C_{Td}$ – consistency at development time, $C_{20}$ – consistency at 20 min. For each parameter, values followed by the same letter are not significantly different at ($p$<0.05).

**Table 7 –** Effect of maize variety and milling type on specific volume, colour parameters and crumb firmness of *broa*

| Variety | Specific Volume ($cm^3/g$) | L* | a* | b* | Firmness (g force) |
|---|---|---|---|---|---|
| *Fandango* | $1.44^{a}$ | $66.7^{c}$ | $-1.05^{c}$ | $30.9^{a}$ | $1503^{b}$ |
| *Pigarro* | $1.46^{a}$ | $71.1^{a}$ | $-0.34^{a}$ | $16.2^{c}$ | $1800^{a}$ |
| Yellow hibrid | $1.40^{a}$ | $65.6^{d}$ | $-1.25^{d}$ | $27.1^{b}$ | $1778^{ab}$ |
| White hibrid | $1.57^{a}$ | $68.9^{b}$ | $-0.74^{b}$ | $15.6^{d}$ | $1611^{ab}$ |

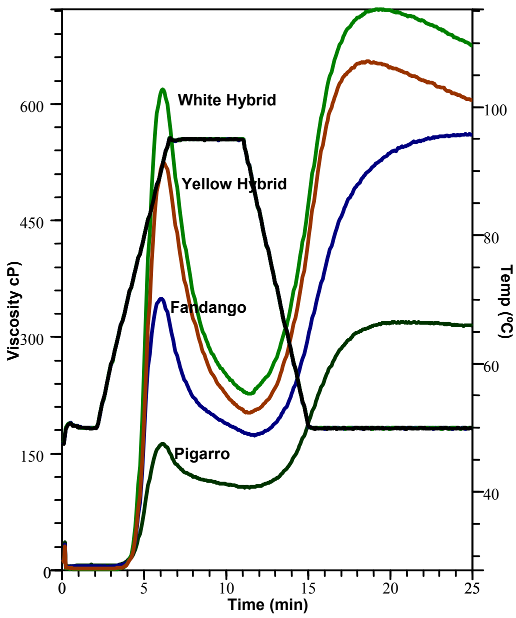
For each parameter, values followed by the same letter are not significantly different at $p<0.05$.

## Figure captions

**Figure 1.** Viscosities profiles of maize flours obtained from electric mill determined by RVA (Rapid Visco Analyser).

**Figure 2–** Crumbs of *broa* produced with traditional and gluten free formulation. Upper pictures: *Fandango* maize variety, and lower pictures: *Pigarro* maize variety.

Figure 1.



White Hybrid
Yellow Hybrid
Fandango
Pigarro
Viscosity cP
Temp (°C)
Time (min)
0
150
300
450
600
40
60
80
100
0
5
10
15
20
25

Figure 2.