

1 **MAIZE BASED GLUTEN FREE BREAD: INFLUENCE OF PROCESSING**
2 **PARAMETERS ON SENSORY AND INSTRUMENTAL QUALITY**

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5 **Carla Brites^{1*}, Maria João Trigo¹, Carla Santos¹, Concha Collar², Cristina M.**
6 **Rosell²**

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8 ¹**Instituto Nacional dos Recursos Biológicos, I.P., L-INIA, Unidade Tecnologia**
9 **Alimentar, Quinta do Marquês, 2784-505 Oeiras, Portugal.**

10 ²**Institute of Agrochemistry and Food Technology (IATA-CSIC). PO Box 73, 46100-**
11 **Burjasot (Valencia), Spain.**

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13 **Running title: Maize based gluten free breads**

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15 *** Corresponding author. Tel: +351214403684; fax:+351214413208**

16 **E-mail address: carlambrites@mail.telepac.pt**

17 **Abstract**

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

37

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

39 **1. Introduction**

40 Wheat proteins have the unique properties of developing a viscoelastic matrix when wheat
41 flour is mechanically mixed with water. This viscoelastic network enables the dough to
42 hold the gas produced during the fermentation process, leading to an aerated crumb bread
43 structure. Unfortunately, gluten must be kept apart from the diet of celiac patients, who
44 suffer very important intestinal damage when they ingest gluten containing products. This
45 technological obstacle has been overcome by using complex bread recipes with different
46 starches and cereal flours like corn starch, brown rice, soy and buckwheat flour (Gallagher
47 et al., 2004; Moore et al., 2006), or a composite blend of rice flour with corn and cassava
48 starches obtaining gluten-free bread with a well structured crumb and pleasant flavour and
49 appearance (Sanchez et al., 2002; Lopez et al., 2004). Generally, in the performance of
50 gluten free bread, a variety of hydrocolloids or gums have been used for creating a
51 polymer network with similar functionality than the wheat gluten proteins. In fact, gluten
52 free breads have been successfully developed using several combinations of cellulose
53 derivatives (Gujral & Rosell, 2004a, Schober et al., 2007). With the same purpose,
54 crosslinking enzymes (glucose oxidase and transglutaminase) have been used as
55 processing aids for improving rice based gluten free bread quality (Gujral and Rosell,
56 2004a,b; Moore et al., 2006). Lately, different proteins have been proposed as alternative
57 for both playing the polymer role and increasing the nutritional value of gluten free
58 products (Marco & Rosell, 2008a, b, c).

59 It is clear that the common player when gluten free breads are developed is the presence of
60 a polymer with certain viscoelasticity and ability to entrap the other components of the
61 system; and usually they are incorporated as ingredients of the recipe. Nevertheless, an
62 attractive alternative would be to perform gluten free breads by using only gluten free

63 cereals and to generate ‘in situ’ during the breadmaking process the required holding
64 biopolymer.

65

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

81

82 Maize is a gluten free cereal, thus suitable to produce foods addressed to celiac patients.
83 The acquired knowledge on *broa* (made from composite maize-rye-wheat flour) is
84 important for facing the challenges in producing gluten-free bread that usually exhibits
85 compact crumb texture and low specific volume (Rosell & Collar, 2007; Rosell & Marco,
86 2008). Therefore, a better understanding of this breadmaking process would provide the
87 basis for developing gluten free bread based on maize flour.

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

92

93 **2. Material and Methods**

94 **2.1. Maize flours characteristics**

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

100 Flour protein and ash content were determined in triplicate following ICC standard
101 105/2:1994 and 104/1:1990 methods. Apparent amylose content was determined
102 following the ISO 6647-2:2007 using 720nm as wavelength, and a calibration curve
103 previously performed with maize flour samples according to ISO 6647-1:2007.

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

110 Maize flour colour was determined on 10-12g of sample in an opaque recipient by using a
111 Minolta Chromameter CR-2b. Maize flour tristimulus colour parameters included: L* -
112 lightness, a* - red/green index, b* - yellow/blue index and ΔE – colour total variation

113 relative to a white surface reference ($L^*=97.5$ $a^*=-0.13$ $b^*=1.63$). Values are the mean of
114 10 replicates.

115

116 **2.2. Dough rheological properties**

117 Dough rheological properties were evaluated in a conventional Brabender farinograph®
118 (Duisburg, Germany) following the method ISO 5530-1:1997 with some modifications.

119 Maize flour (40g) were mixed in the Farinograph 50g bowl with 44mL of distilled water
120 (110% flour basis) during 20min. Assays were carried out under two different conditions,
121 at 25°C and by adding boiling water (100°C). The parameters obtained from the
122 farinogram included Td (development time in minutes, time to reach the maximum
123 consistency), the dough consistency at the Td (C_{Td}) and the consistency after 20min
124 mixing (C_{20}), both in BU (Brabender Units).

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

137 Chen & Hosney cell with a cylindrical probe of 25mm diameter (Armero & Collar,
138 1997).

139

140 **2.3. Breadmaking process**

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

151 Breadmaking process consisted in mixing the maize flour with 77% (v/w, flour basis)
152 boiling water containing 2.2% salt, for 5 minutes in the bowl of Kenwood kitchen
153 Machine. Dough was left idle till cooling to 27°C, then the remaining ingredients
154 (including 18 % water containing 2.2 % salt and 10 % w/w flour basis of sourdough) were
155 added and dough was kneaded again for 8 min and left resting for bulk fermentation at
156 25°C for 90min. After fermentation, the dough was manually moulded in balls of 400g and
157 baked in the oven (Matador, Werner & Pfleiderer Lebensmitteltechnik GmbH) at 270°C
158 for 40min. For each trial, three samples were produced and analysed separately.

159 An adapted breadmaking process was carried out for obtaining gluten free maize bread, in
160 which rye and wheat flours were replaced by maize flour and recipe contained 110 %
161 (v/w, flour basis) of water, identical proportion of the other traditional *broa* ingredients

162 (sugar, salt, improver, dry yeast). Gluten free baking trials were performed with *Pigarro*
163 and *Fandango* maize varieties milled in artisan water mills (n=2).

164

165 **2.4. Bread analyses**

166 Quality technological parameters of breads were determined the following day to its
167 production. Quality parameters included: weight (g), volume (cm³) using polyethylene
168 spheres displacement method (Esteller & Lannes, 2005). Specific volume was then
169 calculated in cm³/g.

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

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

178 Sensory analysis (ISO 8587, 1988) was conducted with a panel of twelve trained judges
179 that quantify the influence of different maize varieties on overall differentiation of *broa*
180 and maize bread. Triangular assays (AACC 33-50A, 1999) were carried out for each
181 maize variety subjected to the two types of milling. Paired comparison tests (ISO 5495,
182 1983) were conducted to compare different varieties (within each colour group- white or
183 yellow), panelists were asked to ranking the samples based on overall texture, taste and
184 aroma. Traditional *broa* was compared with gluten free maize bread.

185

186 **2.5 Statistical analysis**

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

196

197 **3. Results and discussion**

198 **3.1. Effects of maize varieties and milling types on flour composition, colour and** 199 **viscosities**

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

206

207 Significant differences between maize varieties were detected for protein and amylose
208 contents ($P < 0.05$) (Table 2). Regional varieties (*Fandango*, *Pigarro*) exhibited significant
209 higher protein content and lower amylose content than hybrids. *Pigarro* flour had the
210 highest ash content probably due to its endosperm of flint type. Type of milling influenced
211 significantly ($P < 0.05$) the ash content that affects pH profile during fermentation and, in

212 turn, will influence bread quality. The type of grinding did not have any influence on
213 protein and amylose content.

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

220 Viscosity profile of four maize flours during a heating-cooling cycle was recorded by
221 using the rapid viscoanalyzer (RVA) (Figure 1). Compared with commercial wheat flour
222 (results not shown) maize flour exhibited lower pasting temperature, lower maximum
223 viscosity and higher final viscosity, therefore higher setback was obtained. Similar results
224 were obtained by Martínez & el-Dahs (1993), who detected a reduction of the maximum
225 viscosity and an increase in the final viscosities of the wheat flour when adding instant
226 maize flour (up to 25%). When compared the viscosity profile of the different maize
227 varieties, maximum and final viscosities values from hybrid varieties were significantly
228 ($P < 0.05$) higher than those of the regional ones (*Fandango*, *Pigarro*) (Table 4). Flint
229 maize varieties have harder endosperm than the dent varieties and their flours have distinct
230 viscosity profile (Brites et al., 2007a,b). *Fandango* maize flour variety (regional dent type)
231 presented superior values than *Pigarro* (regional flint type), agreeing to previously data
232 (Santos, 2006; Brites, 2006). Previous findings reported that the flint maize shows lower
233 maximum viscosity and lower setback than dent varieties (Almeida-Domingués et al.,
234 1997; Sandhu et al., 2007; Brites et al., 2007b).

235 The milling type variation influenced maximum viscosity (Table 4) and also breakdown,
236 being the average values of the flour from water mill higher and significantly different

237 than the results of flour from the electric mill. The electric milling process yielded flour
238 with lower viscosity profile likely associated to the negative impact of damage starch on
239 the ability to absorb water.

240

241 **3.2. Effects of maize varieties, milling type and water temperature on dough** 242 **farinograph and texture parameters**

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

248 The temperature of the added water for making the dough was the major factor of
249 variability (Table 6). Water temperature significantly ($P<0.05$) affected development time
250 (T_d), the consistency of the dough (C_{Td}) and the stability of the dough (related to the
251 consistency after 20 min mixing). Concerning dough machinability, the temperature of the
252 dough did not significantly affect hardness, but resulted in a significant ($P<0.05$) effect on
253 adhesiveness, gumminess and stickiness of the dough. When boiling water was used for
254 dough mixing, maize dough showed significantly ($P<0.05$) higher consistencies with
255 minor development times compared to doughs mixed at 25°C dough. Associated with the
256 increase of the water temperature was the increase of mechanical and surface related
257 parameters adhesiveness, elasticity, and stickiness and subsequent reduction of
258 cohesiveness. These results were not unexpected since previous studies reported that
259 dough rheological parameters were particularly affected by starch gelatinisation (Miyazaki
260 & Morita, 2005). The addition of boiling water to the maize flour promoted the partial
261 gelatinization of the starch, increasing the viscosity of the dough, consequently, leading to

262 higher dough consistency. The gelatinization occurs as the temperature rises, which
263 increases mechanical strength of dough. This is an important factor to consider when
264 maize flours are destined to gluten free breadmaking obtaining a viscous system that holds
265 the components of the system. In fact, Rosell & Marco (2007) observed a decrease in the
266 peak of maximum viscosity after heating rice flour dough prepared by using heated water
267 during mixing, due to the previous partial gelatinization when warm water was added.
268 Similar effects have been observed when the pasting characteristics of native and heat-
269 moisture treated maize starches were compared (Hoover & Manuel, 1996). As a
270 consequence of the initial starch gelatinization, dough consistency increases, improving
271 the mechanical and handling properties of the rice flour dough compared to those of the
272 dough mixed with water at 25°C (Marco & Rosell, 2008a)

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

281

282 **3.3. Effect of maize varieties and milling types on bread specific volume, colour,** 283 **firmness and sensory assessment**

284 A preliminary breadmaking study was performed varying the temperature (25°C or
285 100°C) of the water added to the maize flour during mixing, *broa* obtained by adding
286 water at 100°C showed superior crumb texture quality than the ones obtained at 25°C

287 water temperature (results not showed). Further breadmaking trials were made following
288 the traditional *broa* making procedure, using boiled water for mixing maize flour.

289

290 Traditional ethnic bread, *Broa*, was made for defining breadmaking conditions prior to the
291 performance of gluten free maize bread because although does The specific volume of the
292 *broa* ranged from 1.40 to 1.57cm³/g (Table 7), which could be considered low values if
293 compared with wheat bread loaves. Traditionally, *Broa* is a type of bread with high
294 density and closed crumb cells, thus high specific volume is not desirable. Besides breads
295 made or containing high amounts of gluten free cereals show low specific volume
296 compared to the ones obtained with wheat flour (Marco & Rosell, 2008a).

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

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

311

312 From the above results, *Fandango* and *Pigarro* varieties were selected for performing
313 gluten free maize bread, since they were the preferred varieties by the judges. The study
314 was restricted to the maize flours from water mill, because milling type did not induce
315 significant differences on the *broa* quality. The specific volume of gluten free maize bread
316 ranged from 1.02 to 1.12 cm³/g. As expected the gluten free breads presented from 20 to
317 30% less specific volume than their counterparts produced with the traditional recipe
318 (obtained from composite maize-rye-wheat flour). Sanni *et al* (1998) obtained maize bread
319 containing egg proteins with 0.95 cm³/g specific volume. Similar bread specific volume
320 had been reported in rice based breads, which were improved by using crosslinking
321 enzymes (Gujral & Rosell, 2004 a,b), hydrocolloids (Marco *et al*, 2007) or proteins
322 (Marco & Rosell, 2008 a).

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

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

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

345

346 **4. Conclusions**

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

356 Baking assays demonstrated that *broa* breadmaking technology could be satisfactorily
357 applied to produce gluten free *broa*. An important point in the breadmaking process was
358 the blanching that resulted in doughs with higher consistency, because in the absence or
359 reduced amount of gluten the dough rheological properties are provided by the starch
360 gelatinisation. Maize based gluten free bread were obtained following *broa* breadmaking

361 process, obtaining bread with satisfactory sensory characteristics and similar appearance
362 than the traditional *broa*.

363

364 **5. Acknowledgements**

365 Authors thank the Cerealis Group enterprises (Nacional, Lisboa, Portugal) for supplying
366 ingredients and baking facilities, Armando Ferreira for support on *broa* crumb texture
367 assessment and colleagues of department for sensory analysis. Authors thank the financial
368 support of the joint research program between the Spanish/Portugal Scientific Research
369 Council (CSIC, Spain; Grices, Portugal); Comissão Interministerial de Ciência y
370 Tecnología Project (MCYT, AGL2005-05192-C04-01) and Programa Operacional
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480

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

481

Variety	Type	Endosperm	Color
<i>Pigarro</i>	Regional, local germplasm, open pollinated	Flint	White
<i>Fandango</i>	Regional, exotic germplasm, open pollinated	Dent	Yellow
Yellow Hybrid	Hybrid	Dent	Yellow
White Hybrid	Hybrid	Dent	White

482

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

485

Factor	Level	Protein (% db)	Ash (% db)	Amylose (% db)
Variety	<i>Fandango</i>	9.5 ^b	1.50 ^b	28.6 ^b
	<i>Pigarro</i>	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

486

487 For each parameter and single factor, values followed by the same letter are not significantly different at
 488 $p < 0.05$.

489

490

Table 3 – Effect of maize variety on colour parameters.

491

492

Variety	L*	a*	b*
<i>Fandango</i>	87 ^b	-1.49 ^c	38.7 ^a
<i>Pigarro</i>	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

493

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

495

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

498

Factor	Level	Maximum Viscosity (cP)	Minimum Viscosity (cP)	Final Viscosity (cP)	Breakdown (cP)
Varieties	<i>Fandango</i>	2999 ^b	1391 ^c	4675 ^b	1609 ^b
	<i>Pigarro</i>	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

499

500 For each parameter and single factor, values followed by the same letter are not significantly different at
 501 $p < 0.05$.

502

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

504

Variety	Milling type	Water temperature (°C)	Td (min.)	C_{Td} (BU)	C₂₀ (BU)	Hardness (g/force)	Adhesiveness (g/s)	Gumminess	Stickiness (g/force)
<i>Fandango</i>	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
<i>Pigarro</i>	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

505

Td – development time (min), C_{Td} – consistency at development time, C₂₀ – consistency at 20min

506

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

508

	Water temperature	
	25°C	100°C
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

509

510 Td – development time, C_{Td} – consistency at development time, C₂₀ – consistency at 20
511 min. For each parameter, values followed by the same letter are not significantly different
512 at ($p < 0.05$).

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

514 and crumb firmness of *broa*

515

Variety	Specific			b*	Firmness (g force)
	Volume (cm ³ /g)	L*	a*		
<i>Fandango</i>	1.44 ^a	66.7 ^c	-1.05 ^c	30.9 ^a	1503 ^b
<i>Pigarro</i>	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}

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

517

518 **Figure captions**

519

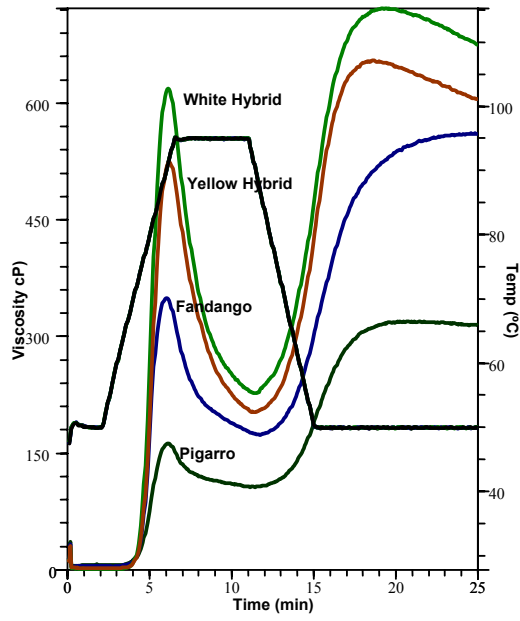
520 **Figure 1.** Viscosities profiles of maize flours obtained from electric mill determined by
521 RVA (Rapid Visco Analyser).

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

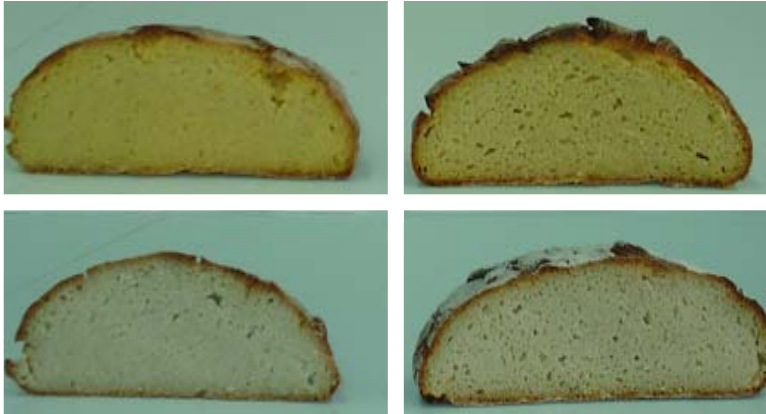
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525 Figure 1.

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547 Figure 2.
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Gluten free

Traditional

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