Physicochemical Properties of Long Rice Grain Varieties in Relation to Gluten Free Bread Quality

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Abstract

The aim of this study was conducted to determine the breadmaking potential of six long-grain rice varieties (INIAP 14, INIAP 15, INIAP 16, INIAP 17, F09 and F50) and to identify any flour characteristic governing their breadmaking behavior. Pasting parameters, thermal parameters assessed by differential scanning calorimetry and bread quality parameters (specific volume, color, and crumb texture profile analysis) were assessed. Results confirmed the suitability of long-grain rice varieties for breadmaking. Nevertheless, significant differences were observed in flour properties among varieties. A significant correlation was observed between specific volume of the gluten-free bread (GFB) with swelling power (r=0.71, P<0.01), breakdown viscosity (r=-0.97, P<0.01) and conclusion temperature (Tc) of gelatinization (r=0.81, P<0.05). Moreover, a strong correlation was found between cohesiveness and properties of rice flour such as peak temperature (Tp) (r=-0.96, P<0.001), ΔH (r=0.71 P<0.05) and swelling volume (r=0.82, P<0.05). The quality characteristics of the gluten-free breads made of long-grain rice flour were comparable to those reported in commercial GFB. INIAP 14 and F09 were the most promising varieties for bakery applications. Results suggested that the most important parameters of rice flour when defining breadmaking performance of GFB would be WBC, SP, SV, Tp, Tc and enthalpy.

Key words: rice flour; variety; bread; gluten-free; quality.

1. Introduction

Rice is mainly consumed as cooked rice, but during the last decade the consumption of rice flour has increased due to its application in breadmaking. Rice has unique sensorial and nutritional advantages for developing gluten-free foods. Specifically, rice flour has a neutral flavor, low levels of sodium, easy digestibility, hypoallergenic proteins, and does not contain gluten. These characteristics make rice flour a suitable ingredient for gluten-free bakery products (Marco & Rosell, 2008). However, features of rice based breads are greatly dependent on rice flour functionality. Physicochemical properties of rice flour, main determinants of its technological functionality, are greatly variable. In fact, these properties are significantly influenced by rice variety (Han, Cho, Kang & Koh, 2012; Sompong, Siebenhandl-Ehn, Linsberger-Martin & Berghofer, 2011; Yu, Ma, Menager & Sun, 2012), storage conditions (Park, Kim, Park & Kim, 2012; Tananuwong & Malila, 2011), particle size of the flour and length of rice grain (de la Hera, Gomez & Rosell, 2013a), processing method (Guha & Ali, 2011), chemical structure and composition (Kim, Song & Shin, 2010; Zhu, Liu, Sang, Gu & Shi, 2010), among others.

Regarding variety, there is a general agreement that rice grain length is a factor that influences the bread quality in gluten-free breads (GFB), although discrepancies about the most convenient type of rice grain have been reported (Kadan, Robinson, Thibodeaux & Pepperman, 2001; Rosell & Gomez, 2006; de la Hera, Martinez & Gómez, 2013b). In general, the size of the grain is related to its amylose content. Long-grain rice contain higher amylose content and gelatinization temperature, as well as more tendency of retrogradation than short-grain rice. Noomhorm, Bandola & Kongseree (1994) demonstrated that rice varieties with low amylose content exhibited low gelatinization temperature and soft gels, which was beneficial for baking. Kadan et al. (2001) reported that combining part of the long-grain variety with 10% of short-grain variety produces a smoother texture in bread. Furthermore, Han et al. (2012) stated that intermediate amylose content and low water absorption capacity of rice gave better rice bread physicochemical properties. Studies had shown that short and medium-grain rice varieties presented better bread textures (Rosell et al., 2006). de la Hera et al., (2013b) showed that short-grain rice produced breads with higher specific volume and lower hardness than long-grain rice. Conversely, few studies demonstrated that long-grain rice could have good breadmaking performance (Han et al., 2012; Kadan et al., 2001; Sivaramakrishnan, Senge, & Chattopadhyay, 2004). In fact, Sivaramakrishnan et al. (2004) reveal that flour of long-grain rice with 3g of hydroxypropylmethylcellulose per 100g of flour presents better texture than flour of short-grain rice. Generally, studies related to rice gluten-free bread have been carried out with commercial rice flour, without controlling the rice type or variety (de la Hera et al., 2013b; Kadan et al., 2001; Rosell et al., 2006). Since there is not knowledge about the main properties of rice flour governing breadmaking potential, it is necessary to get additional insight on the properties of rice flour from long-grain varieties.

Therefore, the aim of this study was to determine the breadmaking potential of six long-grain rice varieties and to assess any possible flour characteristic (physicochemical and rheological) of their breadmaking behavior.

2. Materials and Method

Six varieties of long-grain rice were selected as representative of the main production in the region. Four of them were from the National Institute of Agricultural Research from Ecuador (INIAP, Boliche, Ecuador): INIAP 14, INIAP 15, INIAP 16 and INIAP 17 and two varieties were from the company PRONACA (Guayaquil, Ecuador): F09 and F50. The average size of the rice grains was

7.2mm±0.1mm. All varieties were harvested between May and December of 2011. All the samples were provided by INIAP.

2.1. Flour production and chemical characterization

The seeds were polish and milled (Cyclotec Sample Mill, Tecator, Hoganas, Sweden) with a 500 μm screen. Considering the already stated relationship between physicochemical properties of starches and their apparent amylose content (AAC), protein and lipid (Gani, Wani, Masoodi & Salim, 2013, Tester & Morrison 1990a, Kim et al. 2010), these parameters have been analyzed. The flour protein, lipid content and moisture content were analyzed following AOAC methods (AOAC 18th 92087 for protein and AOAC18th 922.06 for fats). Moisture content was determined following the ISO method (ISO 712:1998). The AAC of the rice flour was measured following the iodine calorimetric method (Juliano et al., 1981). Spectrophotometer (PerkinElmer, Waltham, USA) measurements were made at 620nm after the above starch-iodine solution was incubated for 20min at ambient temperature. Standard curve was generated using starch reference with 66g of amylose per 100g of flour from the Megazyme kit K-AMYL 04/06t (Megazyme International Ltd, Wicklow, Ireland). All the analyses were made by triplicate.

2.2. Flour hydration properties

The water holding capacity (WHC) defined as the amount of water retained by the sample without being subjected to any stress was determined by mixing (1.000g ± 0.005g) of flour with distilled water (10ml) and kept at room temperature for 24h. The supernatant was carefully removed with a pipette. WHC was expressed as grams of water retained per gram of solid. The swelling volume (SV) was determined following the method reported by Gularte & Rosell (2011) with slight modification. The swelling volume was calculated by dividing the total volume of the swollen sample after 24h at room temperature by the powder weight of the sample. The water binding capacity (WBC) defined as the amount of water retained by the sample under low-speed centrifugation was determined as described the standard method (AACC, 2010). Samples (1.000g ± 0.005g) were mixed with distilled water (10ml) and centrifuged at 2,000xg for 10min. WBC was expressed as grams of water retained per gram of solid. All the analyses were made by triplicate. WHC, SV and WBC were calculated by the equations 1 to 3:

$$\text{WHC (g/g)}=\frac{\text{Weight of sediment after draining supernatant -Sample dry weight}}{\text{Sample weight}} \quad \text{Eq. 1}$$

$$\text{SV (ml/g)}=\frac{\text{Total volume of swollen sample}}{\text{Sample weight}} \quad \text{Eq. 2}$$

$$\text{WBC (g/g)}=\frac{\text{Weight of sediment after centrifugation -Sample dry weight}}{\text{Sample weight}} \quad \text{Eq. 3}$$

2.3. Flour gelling behavior

Water absorption index (WAI), water solubility index (WSI) and the swelling power (SP) of different rice flour gels were determined following the method of Anderson, Conway, Pheiser & Griffin (1969), with slight modification. Briefly, flour (50.0mg ± 0.1mg) sample was dispersed in 1ml of distilled water and cooked at 90ºC for 15min in a water bath. The cooked paste was cooled to room temperature, and centrifuged at 3,000xg at 4°C for 10min (Thermo Scientific, Walthman, USA). The supernatant was decanted for determination of its solid content into an evaporating dish and the sediment was weighed. The weight of dry solids recovered by evaporating the supernatant overnight at 110ºC was determined. Four replicates were made for each sample. WSI, WAI and SP were calculated by the equations 4 to 6:

$$W\text{AI (g/g)} = \frac{\text{Weight of sediment}}{\text{Sample weight}} \quad \text{Eq. 4}$$

$$W\text{SI (g/g)} = \frac{\text{Weight of dissolved solids in supernatant}}{\text{Sample weight}} \quad \text{Eq. 5}$$

$$SP\ \text{(g/g)} = \frac{\text{Weight of sediment}}{(\text{Sample weight}-\text{Weight of dissolved solids in supernatant})} \quad \text{Eq. 6}$$

For the determination of oil absorption capacity (OAC), the method of Lin et al. (1974) was followed and it was expressed as grams of oil bound per gram of the sample on dry basis. Three replicates were made for each sample. OAC was calculated by the equation 7:

$$OAC\ (g/g) = \frac{\text{Weight of sediment after draining oil}}{\text{Sample weight}} \quad \text{Eq. 7}$$

2.4. Determination of pasting properties of rice flours

Pasting properties of the rice flour were determined using a rapid visco analyser (RVA) (Newport Scientific model 4-SA, Warriewood, Australia) by following ICC standard method No 162 (ICC, 1996). Sample (3g based on 14g of moisture per 100g of flour) was added to 25mL of water. The mixture was heated to 50°C for 1min and then heated to 95°C at a rate of 12.2°C min^{-1}. After holding at 95°C for 2.5min, the mixture was cooled to 50°C at a rate of 11.8°C min^{-1}. The rotational speed of the paddle was maintained at 160rpm through the run, except during the first 10s, when a 960rpm speed was used. Peak viscosity, breakdown, final viscosity and setback (difference between final viscosity and peak viscosity) were evaluated. Three replicates were carried out per sample.

2.5. Assessment of gelatinization parameters of rice flour

Evaluation of gelatinization was performed by using a TA instruments Q-200 differential scanning calorimeter (Newcastle, USA). Deionized water was added to rice flour (3.0mg) in aluminum pan to obtain a flour/water ratio of 1:3 (w/w, dry weight basis). The pans were hermetically sealed and the samples were allowed to stand for one hour at room temperature before analysis. The scanning temperature range was between 20-130°C to have a good assessment of thermal changes of flour. In order to increase accuracy and resolution without loss of sensitivity of results, 5°C min^{-1} heat rate was used. The calibration was made with indium and the thermogram was recorded using an empty pan as reference. The parameters evaluated were the transition temperatures (the onset (T_0), peak (Tp) and conclusion (Tc), gelatinization temperature range (Ig) and the enthalpy of gelatinization (ΔH). In addition, the peak height index (PHI) was calculated by equation 9. PHI provides a numerical value that is descriptive of the relative shape of the endotherm. A tall narrow endotherm has a high PHI than a short one does, even if the energy involved in the transition is the same (Krueger, Knutson, Inglett & Walker, 1987). High PHI value could be related to more structured starch matrix (Correia & Beirão-da-Costa, 2012). All DSC experiments were replicated at least three times.

$I_g = T_c - T_0$ Eq. 8

$PHI = \frac{\Delta H}{T_p - T_0}$ Eq. 9

2.6. Breadmaking and evaluation of bread quality

Compressed yeast supplied by LEVAPAN (Guayaquil, Ecuador) and hydroxypropylmethylcellulose (Methocel, K4M) provided by Dow Chemical Company (Michigan, USA) were used for breadmaking. The dough was performed using the recipe reported by Marco et al. (2008) (table 1). Half of the rice flour was mixed with boiling water (half of the water) for 5min in Oster blender model 2700 (Oster, Boca Raton, USA) with dough hooks set at low speed (position 1). The dough was left to rest until the temperature decreased to 30°C. Then, the rest of the flour, the other ingredients and water were added and mixed for 5min, set at low speed (position 1). Later, dough were put into pans and fermented for 40min at 35°C and 85% RH. Finally, the fermented dough was baked for 35min at 175°C. Breads were analyzed after 24h of baking.

The analyzed bread characteristics included specific loaf volume, crumb color and crumb texture parameters. The loaf volume was determined by rapeseed displacement, while the specific volume (ml x g^{-1}) was calculated as the ratio of the volume (ml) to the weight (g) of the bread. The crumb color was determined by the computer vision system (Yam & Papadakis, 2004). The computer vision system station included a light source, a camera (canon SX500 IS, 16 mega pixel, Tokio, Japan) for image acquisition and software (Adobe Photoshop CS5) for image processing and analysis. The software quantify the color of crumb in the CIE-L^* a^* b^* uniform color space (CIE-

Lab), where $L*$ indicates lightness, $a*$ indicates hue on a green (−) to red (+) axis, and $b*$ indicates hue on a blue (−) to yellow (+) axis. Data from three slices per bread were averaged. Additionally the cylindrical coordinates: hue and Chroma ($C*_{ab}$) were defined by the following equations:

$$C_{ab}^{*} = \sqrt{a^{*2} + b^{*2}} \qquad \text{Eq. 10}$$

$$Hue = \arctan\left(\frac{b^{*}}{a^{*}}\right) \qquad \text{Eq. 11}$$

Hue angle is the angle for a point calculated from $a*$ and $b*$ coordinates in the color space. Chroma is the quantitative component of the color, which reflected the purity of color in the CIELAB space. Texture measurements in form of texture profile analysis (TPA) (Bourne, 1978), of the breadcrumbs was performed by a Texture Analyzer CT3 (Brookfield, Middleboro, USA). A bread slice of 1cm thickness was compressed up to 50% of its original height at a crosshead speed of 1mm/s with a cylindrical acrylic probe (diameter 25.4mm). From the TPA curves, the following texture parameters were measured: hardness (N), springiness, cohesiveness, resilience and chewiness (N). Hardness was defined by peak force during first compression cycle. Cohesiveness was calculated as the ratio of the area under the second curve to the area under the first curve. Springiness was defined as a ratio of the time recorded between the start of the second area and the second probe reversal to the time recorded between the start of the first area and the first probe reversal. Chewiness was obtained by multiplying hardness, cohesiveness and springiness. Resilience was calculated as the area during withdrawal of the penetration, divided by the area of the first penetration.

2.7.Statistical analysis

Standarized skewness and standarized kurtosis analyses were made to verify normal distribution of the data. Multiple sample comparison was conducted to evaluate significant differences among samples by analysis of variance (ANOVA) and multiple range tests. Fisher's least significant differences (LSD) test was used to describe means with 95% confidence (*P*<0.05). Data was also evaluated using Pearson correlation coefficients to establish relationship among variables. Only correlation coefficients (in absolute value) equal or greater than 0.68 were considered meaningful. All statistical analyses were performed using Statgraphics Centurion 16 (Statistical Graphics Corporation, UK).

3. Results and Discussion

3.1. Protein, fat and apparent amylose content

In order to understand the possible role of rice grain composition on the flour functionality, protein, fat and apparent amylose content (AAC) of the rice flour varieties were determined (table 2). There was a significant difference in the chemical composition among all the varieties especially in the protein content, which ranged from 5.4 to 8.0g of protein per 100g of flour. The F09 followed by INIAP 14 and INIAP 17 showed the highest amount of protein. Apparent amylose content varied between 22.7 to 28.1g per 100g of flour. Thus, all varieties could be considered as intermediate to high amylose content, in agreement with values reported for long-grain rice (Wani et al., 2012). The highest value was found in the INIAP 17 and F09. On the other hand, the fat content ranged from 0.5 to 1.0g of fat per 100g of flour. No significant difference in AAC and lipid content were found among INIAP 14, INIAP15 and INIAP 16.

3.2. Flour and flour gel hydration properties:

The hydration properties of the rice flours and the rice gels are shown in table 3. No statistical difference in oil absorption capacity (OAC) and water solubility index (WSI) were observed among varieties.

The lowest value of water binding capacity (WBC) was displayed by INIAP 17, which is the variety with the highest amylose content. In fact, some researchers have reported that an increase in amylose level results in reduced water binding (Gani et al. 2013; Iturriaga, Lopez, & Añon, 2004). However, the INIAP 14, which has the lowest amylose content, did not follow that trend, likely other intrinsic factors such as particle size, protein conformation, lipid and protein content and lipid-amylose complex are affecting this capacity (Gani et al., 2013; Tester et al., 1990a). Actually, no correlation was found between WBC with protein, fat and AAC, implying that the synergic effect of these entire factors influence the WBC.

The WBC of the flour has been related to stickiness of rice flour dough, high WBC reduces stickiness and produces stiff dough (Han et al., 2012). The values for WBC were higher than the ones reported by Han et al. (2012), who showed that rice lines with low WBC produce fresh bread with suitable volume and firmness. On the other hand, INIAP 17 showed the highest value of WHC, thus could retard staling in gluten-free bread (Sciarini, Ribotta, León, & Pérez, 2010). There was no significant difference on SV among INIAP 17, F09 and F50 varieties and among INIAP 14, INIAP 15 and INIAP 16, which presented lower SV value.

INIAP 14, which had the lowest AAC, presented the highest SP value. This result agrees with previous reports describing that high amylose content inhibits swelling power (SP) of cereal starch (Tester & Morrison, 1990b; Singh, Kaur, Sandhu, Kaur & Nishinari, 2006). However, when correlation matrix was carried out, no significant correlation was found between the apparent amylose content and the SP. Therefore, result might be derived from the effect of starch content, protein content, bounding forces and molecular structure of starch, especially of the amylopectin (Kim et al., 2010).

The correlation analysis indicates a positive correlation parameter between SP and WAI (r=0.89, P<0.001) and negative correlation between SP and WBC (r=-0.68, P<0.01) as well as WAI and WBC (r=-0.68, P<0.01). Previous reports indicate that WBC of flours depends on the hydrophilic parts of proteins and carbohydrates (Wani, Sogi, Wani & Gill, 2013), water is absorbed in the amorphous zone of the starch and become swollen prior to any change in the small crystallites facilitating the striping of chains and melting of crystallites (Iturraga et al., 2004). As water increases in amorphous region SP increases (Kim et al., 2010). Presumably, in flours with high WBC, water become less available to hydrate the amorphous region of the starch, during the hydration and gelatinization of the flour; therefore the SP and WAI decrease. The INIAP 14 and INIAP 17 showed high values of WAI and SP. It has been reported that high absorption of water during baking can enhance initial softness and decrease firming of bread (Arendt, Moore & Dal Bello, 2008).

3.3.Pasting Properties of rice flour

The pasting properties and the pasting curves of the long-grain rice varieties are shown in table 4 and figure 1, respectively. INIAP 14 showed the lowest peak viscosity, and INIAP 17 and F09 the highest one. Nevertheless, no significant correlation was found between pasting properties and the amylose content, which agrees with previous report (Sompong et al., 2011). Negative correlation between peak viscosity and WAI was found (r=-0.77, P<0.01). INIAP 17 also showed high final viscosity value, indicating high capacity to form gel, but with high retrogradation tendency due to its high setback value (Gani et al., 2013). Indeed, a significant correlation between final viscosity and AAC was found (r=0.70, P<0.05), although no with the setback. Result that differed from previously reported (Sompong et al., 2011; Gani et al., 2013).

INIAP 14 and INIAP 17 presented lower breakdown viscosity and F09 the highest. The breakdown is caused by the disintegration of gelatinized starch granule structure during continued stirring and heating. Differences in breakdown among rice starches have been related to differences in rigidity of swollen granules (Gani et al., 2013). A negative correlation was found between breakdown viscosity and SP (r=-0.72, P<0.01). Hence, INIAP 17 and INIAP 14 could lead to bread with high specific volume.

3.4. Gelatinization parameters of rice flour

The gelatinization temperatures (onset, To; peak, Tp; and conclusion, Tc), gelatinization enthalpy (ΔH), gelatinization temperature range (Ig) and peak height index (PHI) of rice flours from different varieties are shown in table 5. Significant differences were observed in the thermal properties due to varieties. Gelatinization temperatures and enthalpy were similar to those reported by other authors for rice flour and starch (Han et al., 2012; Iturriaga et al., 2004; Singh et al., 2006). Variation even of 10°C was found among the onset gelatinization temperatures (To) of the INIAP 14 and INIAP 15 and the other varieties.

Negative correlation between To and Ig was found (r=-0.97, P<0.001). INIAP 14 and INIAP 15 showed high values on To and low on Ig. Considering that INIAP 14 and INIAP 15 showed low amylose content, this result agrees with Krueger et al. (1987), who reported that the high the amylopectin content of the starch, the low temperature range of gelatinization. In addition, negative correlation between Tp and SV was found (r=-0.80, P<0.001). INIAP 14, INIAP 15 and INIAP 16 showed high Tp value, and likely with high resistance to swell.

The enthalpy of gelatinization (ΔH) has been used as indicator of the loss of molecular order within the granule that occurs during gelatinization (Tester et al., 1990 b). INIAP 15 showed the lowest ΔH value, indicating less stability of crystals (Chiotelli & Le Meste, 2002). Peak high index (PHI) provides a numerical value that describes the relative shape of endotherm. INIAP 16 and INIAP 17 showed low peak high index (PHI) values, which can be related to lower structured starch matrix (Kruger et al., 1987). Therefore, INIAP 17 showed low To, PHI and broad Ig that might be due to the presence of irregularly-shaped granules (Kaur, Singh, Sandhu & Guraya 2004). The same analysis could be applied to F09 and F50 varieties. On the other hand, INIAP 14 showed the highest values of To, Tp, ΔH, PHI and narrow Ig, which could indicate high degree of molecular order (Correia et al., 2012; Sandhu, Singh & Kaur, 2004).

Figure 2 shows the endothermic curves of the rice varieties. INIAP 17, INIAP 16, F09 and F50 showed a shoulder peak; like it has been reported in Thai rice variety due to amylopectin structure composed by two different molecular structures (Kim et al., 2010).

No significant correlation was observed between gelatinization parameters and hydration properties, neither with apparent amylose content. Presumably, the presence of protein and lipid in rice flour also influence the gelatinization process, and affect the water- starch bonding (Iturriaga et al., 2004).

3.5 Evaluation of Bread

Figure 3 shows the cross section of breads from all rice flour varieties. INIAP 15 and INIAP 17 showed smaller gas cells, which led to a more compact crumb. F09 had a more flattened surface, indicating lower driving force in the oven, possibly due to weaker mass structure.

The quality characteristics of the breads obtained from rice varieties are shown in table 6. Specific volume values of gluten-free breads (GFB) ranged from 1.80 to 2.41ml/g, which agrees with previously reported (de la Hera et al., 2013b; Matos & Rosell 2012; Sciarini et al., 2010). A significant correlation was observed between specific volume and SP (r=0.71, P<0.01) and breakdown viscosity (r=-0.97, P<0.01). Matos & Rosell (2013) reported also a negative correlation between specific volume and pasting properties assessed with Mixolab. In fact, INIAP 14 presented high specific volume, high SP and low breakdown viscosity. As was reported before by Han et al. (2012), rice lines with low WBC produce fresh bread with a suitable volume and firmness. Whereas INIAP 14 has low WBC and high specific volume, no correlation was found between both properties. In addition, no correlation was found between amylose content and specific volume of the bread. However, the conclusion temperature (Tc) of gelatinization has a positive correlation (r=0.81, P<0.05) with the specific volume. This result could be related with the time that the bread has to increase the volume within the oven.

The color of the crumb has been also an important parameter for characterizing GFB. $L*$ value indicates the lightness of the crumb. Rice flour based breads give a very white crumb, which differs from the wheat flour based crumbs that are yellowish. The $L*$ range (74 to 72) agreed with the ones reported before (Matos et al., 2012). Lower crumb luminosity (65) was reported by Marco et al. (2008) when using short-grain rice flour in the same GFB recipe. The range of $a*$ values were indicating hue on green axis, as was obtained with short-grain rice flour (Marco et al., 2008). On the other hand, the positive range of $b*$ values were within the ones reported for commercial breads, showing hue on yellow axis (Matos et al., 2012). Values of $b*$ ranged from 18 to 21, whereas with short-grain rice flour was around 8, likely due to differences in rice polishing degree (Marco et al., 2008). All the samples showed a negative hue angle that reflected yellow-greenish hue. INIAP 15 presented the major intensity of yellow component, indicated by chroma value.

Significant differences were observed in the crumb texture properties among rice varieties (table 7). Crumb hardness ranged from 3.5N to 10.8N, thus softer crumbs than those reported in commercial GFB (Matos et al., 2012), but harder than GFB made with short-grain rice flour (1.96 ±0.19N) (Marco et al., 2008). INIAP 14, F09 and F50 showed lower hardness values and INIAP 17 the highest one. The range of springiness in the studied rice varieties were in the lower limit of the ranges reported before (Marco et al., 2008; Matos et al., 2012), showing their fragility and tendency to crumble when sliced (McCarthy, Gallagher, Gormley, Schober & Arendt, 2005). High springiness values are preferred because it is related to the freshness and elasticity of the bread. Not only springiness but also resilience characterizes the loss of elasticity, because it indicates the ability of a material to return to its original shape after stressing (Onyango, Mutungi, Unbehend & Lindhauer, 2011). With the exception of INIAP 17, all the INIAP varieties showed significant lower resilience values than F09 and F50. In fact, all varieties showed lower values than the one reported for GFB from long-grain rice (Kadan et al., 2001) and close to the 0.26 resilience value reported for

GFB from short-grain rice (Marco et al., 2008). These results are in the upper level of the result of Matos et al. (2012) in commercial GFB. Chewiness of the rice varieties ranged between 8.97 to 20.26N, those values were within the upper level of commercial GFB (Matos et al., 2012). INIAP 17 showed significantly higher value.

F09 and F50 presented the highest cohesiveness value, which was desirable because it forms a bolus rather than disintegrates during mastication (Onyango et al., 2011). Cohesiveness characterizes the extent to which a material can be deformed before it ruptures, reflecting the internal cohesion of the material. A strong correlation was found between cohesiveness and properties of rice flour such as Tp (r=-0.96, P<0.001), ΔH (r=0.71 P<0.05) and SV (r=0.82, P<0.05).

Therefore, results confirmed that long-grain rice varieties are suitable for obtaining gluten free breads, but rice variety had a significant impact on the GFB characteristics. Among the varieties tested, INIAP 14 and F09 gave the best GFB features, moreover considering specific volume and crumb texture properties.

4. Conclusion

Rice flour from short-grain has been recommended for making gluten-free bread, but present results show that flour from long-grain rice is suitable for making gluten-free bread, having similar characteristics than previously reported GFB made from short-grain rice. Likely, discrepancies could be attributed to the wide use of commercial rice flours instead of using specific rice varieties. Results obtained with six different long- grain rice varieties confirmed their suitability for breadmaking performance. Significant differences were observed within varieties. Results suggested that the most important parameters of rice flour when defining breadmaking performance of GFB would be WBC, SP, SV, Tp, Tc and enthalpy. Technological parameters (hydration and pasting) would not be able to predict specific volume or hardness. Nevertheless, regarding crumb cohesiveness and resilience, it would be advisable to select flours with high swelling value, and enthalpy but low gelatinization peak temperature. In addition, no correlation has found between WBC with hardness and specific volume of the GFB. Flour properties such as SV, Tp and ΔH were strongly related to cohesiveness value, F09 and F50 showed the highest cohesiveness value. Also, high SP and low breakdown viscosity of the rice flour, showed in INIAP 14, are related to high specific volume of the GFB. Previous reports supported that short rice grain was the only suitable for gluten-free breadmaking. Nonetheless, this study indicated that the length of the rice is not a determining factor for breadmaking, and long-grain rice could be used for bakery, indeed it seems that synergic effect of intrinsic factors such as particle size, protein conformation, lipid and protein content and lipid-amylose complex and starch structure that could affect the properties of rice flour. In addition, results suggest that by selecting specific varieties of rice it would be possible to improve the baking performance of the rice flours, and presumably breeding could also be a good tool to obtain new promising varieties for baking.

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FIGURE CAPTIONS

Figure 1: Rapid viscoanalyzer plots showing the pasting behavior of flours from different long-grain rice varieties. Legends: Grey line: temperature; F09 (– – – –); F50 (--------); INIAP 14 (············); INIAP 15 (━━━━); INIAP 16 (–·–·–·–); INIAP 17 (———).

Figure 2: DSC plots showing the endothermic curves of flours from different long-grain rice varieties. Legends: Grey line: temperature; F09 (– – – –); F50 (--------); INIAP 14 (············); INIAP 15 (━━━━); INIAP 16 (–·–·–·–); INIAP 17 (———).

Figure 3: Cross-section of gluten-free breads made of rice flours from different long-grain varieties. Recipe described in Table 1.

Table 1. Gluten-free bread recipe used for breadmaking.

Ingredient	Percentage in flour basis
Rice flour	100
Water	110
Dry yeast	3
Salt	1.8
Sugar	3
Vegetal oil	6
Baking improver (HPMC)	2

Table 2. Proximate composition of flours from different long-grain rice varieties.

Variety	AAC (g/100g)	Protein (g/100g)	Fat (g/100g)	Moisture content (g/100g)
INIAP 14	22.67±1.88c	7.67±0.10b	0.63±0.03c	12.47±0.03d
INIAP 15	23.74±1.15bc	5.43±0.10e	0.59±0.04c	11.53±0.06c
INIAP 16	24.62±1.53bc	6.23±0.06d	0.60±0.05c	10.62±0.14b
INIAP 17	28.16±2.50a	7.67±0.16b	0.47±0.03d	11.65±0.16c
F09	25.65±1.27ab	8.01±0.02a	0.79±0.02b	10.17±0.02a
F50	23.82±0.94bc	7.04±0.04c	0.95±0.05a	10.18±0.11a

AAC: Apparent Amylose Content.
Values with different letters in the same column are significantly different (*P*<0.05) (n=3).

Table 3. Hydration properties of flours and gels from different long-grain rice varieties.

Variety	**WBC (g /g)**	**WHC (g /g)**	**SV (ml/g)**	**WAI (g/g)**	**WSI (g/g) x 100**	**SP (g/g)**	**OAC (g/g)**
INIAP 14	1.28±0.04cd	1.56±0.10cd	2.99±0.00bc	13.34±0.61a	1.74±0.49a	13.58±0.61a	1.76±0.01a
INIAP 15	1.33±0.07abc	1.48±0.05d	2.79±0.19c	5.04±0.28e	2.23±0.77a	5.16±0.32d	1.73±0.05a
INIAP 16	1.38±0.05a	1.74±0.06b	2.93±0.12bc	6.26±0.81d	2.19±0.59a	6.39±0.84c	1.71±0.01a
INIAP 17	1.23±0.02d	1.95±0.15a	3.13±0.12ab	11.65±0.19b	2.73±0.75a	12.07±0.15b	1.71±0.02a
F09	1.35±0.02ab	1.51±0.08d	3.37±0.23a	5.95±0.38d	1.89±0.42a	6.07±0.38c	1.71±0.01a
F50	1.30±0.02bc	1.70±0.09bc	3.27±0.12a	7.49±0.79c	3.00±0.01a	11.73±0.61b	1.77±0.06a

WBC: Water Binding Capacity, WHC: Water Holding Capacity, SV: Swelling Volume, SP: Swelling Power, WAI: Water Absorption Index, WSI: Water Solubility Index, OAC: Oil Absorption Capacity.

Values with different letters in the same column are significantly different (*P*<0.05), (n=3).

Table 4. Pasting Properties of flours from different long-grain rice varieties determined from the RVA plots.

Variety	Peak viscosity (cP)	Breakdown (cP)	Final viscosity (cP)	Setback (cP)
INIAP 14	1692±16d	287±1d	4014±18b	2609±3b
INIAP 15	2731±24c	1083±47b	3683±0d	2035±23d
INIAP 16	2883±10b	989±1b	4079±2b	2184±11c
INIAP 17	2964±29a	580±1c	5356±74a	2972±46a
F09	2971±15a	1237±40a	3803±21c	2069±19d
F50	2822±66b	1040±100b	3874±13c	2092±21d

Values with different letters in the same column are significantly different ($P < 0.05$), (n=3).

Table 5. Gelatinization parameters of flours from different long-grain rice varieties determined from the DSC plots.

Variety	**To (°C)**	**Tp (°C)**	**Tc (°C)**	**ΔH (J/g)**	**Ig (°C)**	**PHI**
INIAP 14	69.0±0.4a	74.1±0.5ab	80.6±0.4a	12.7±2.7ab	11.7±0.7b	2.44±0.31a
INIAP 15	68.5±1.0a	75.2±0.8a	79.8±2.4a	8.6±1.6b	11.4±2.7b	1.39±0.04c
INIAP 16	60.8±2.0b	74.6±0.2ab	81.6±0.8a	11.7±3.3ab	20.9±2.6a	0.84±0.12d
INIAP 17	59.0±0.8bc	73.7±0.2b	79.5±1.2a	12.9±1.8ab	20.5±0.5a	0.88±0.14d
F09	58.4±2.0c	66.8±0.8c	80.9±0.9a	13.9±3.4ab	22.5±2.9a	1.68±0.19c
F50	58.7±0.4bc	66.4±1.0c	81.3±1.2a	16.0±2.8a	22.6±1.5a	2.07±0.04b

To: Onset Temperature, Tp: Peak Temperature, Tc: Conclusion Temperature, ΔH: Enthalpy of gelatinization, Ig: gelatinization temperature range, PHI: Peak Height Index.

Values with different letters in the same column are significantly different (*P*<0.05), (n=3).

Table 6. Technological characteristics of GFB made of rice flour from different long-grain varieties.

Variety	**Specific Volume (ml/g)**	***L****	***a****	***b****	**Chroma**	**Hue angle (°)**
INIAP 14	2.35±0.14a	74.00±0.00a	-3.77±0.58a	18.33±1.55b	18.71±1.08bc	-78.63±2.18a
INIAP 15	2.09±0.02c	72.00±1.00c	-2.67±0.58a	21.00±0.00a	23.82±4.62a	-83.51±1.44b
INIAP 16	2.28±0.03b	72.67±0.58bc	-2.67±0.58a	18.67±0.58b	18.86±0.54bc	-81.85±1.87ab
INIAP 17	1.80±0.02d	73.67±1.15ab	-3.00±0.00a	21.00±0.00a	22.53±2.29ab	-82.30±0.74ab
F09	2.41±0.19a	74.67±0.58a	-3.67±0.58a	18.00±1.00b	18.38±0.89c	-78.41±2.29a
F50	2.24±0.14bc	74.00±0.00a	-3.33±1.15a	19.33±1.53b	19.65±1.34bc	-80.05±3.92ab

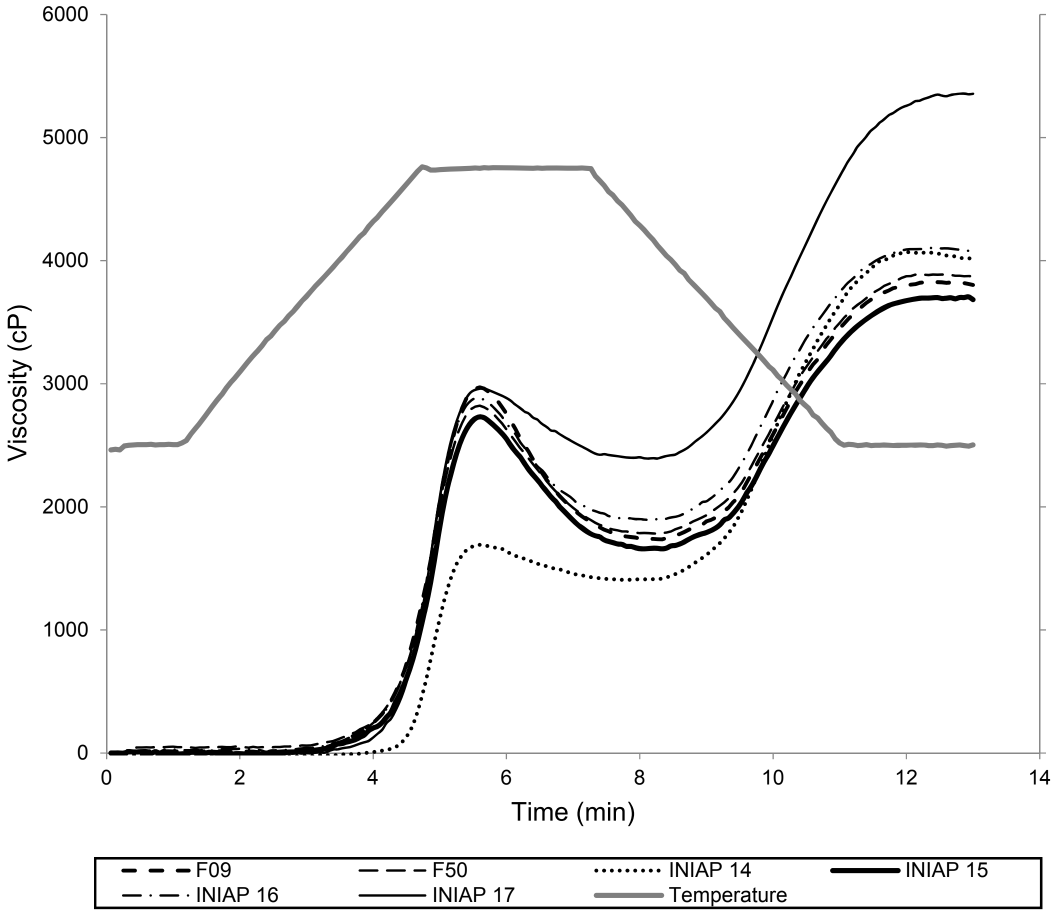
Values with different letters in the same column are significantly different (*P* <0.05), (n=3).

Table 7. Texture profile analysis of crumbs of GFB made of rice flours from different long-grain varieties.

Variety	**Hardness (N)**	**Resilience**	**Springiness**	**Chewiness (N)**	**Cohesiveness**
INIAP 14	5.88±1.79cd	0.23±0.02c	0.73±0.06abc	8.97±2.31c	0.48±0.05bc
INIAP 15	9.67±2.06ab	0.20±0.03c	0.68±0.05c	14.95±2.97b	0.44±0.05c
INIAP 16	7.16±1.31bc	0.21±0.03c	0.70±0.00bc	11.05±2.31bc	0.45±0.04c
INIAP 17	10.84±3.21a	0.29±0.05b	0.75±0.07abc	20.26±6.11a	0.54±0.08b
F09	3.85±0.82d	0.30±0.01ab	0.80±0.00a	9.04±1.87c	0.62±0.01a
F50	3.54±1.06d	0.35±0.02a	0.75±0.06ab	9.16±2.62c	0.67±0.03a

Values with different letters in the same column are significantly different (*P*<0.05), (n=3).

Figure 1


6000
5000
4000
3000
2000
1000
0
Viscosity (cP)
120
100
80
60
40
20
0
Temperature (°C)
0
2
4
6
8
10
12
14
Time (min)
F09
F50
INIAP 14
INIAP 15
INIAP 16
INIAP 17
Temperature

.

Figure 2.

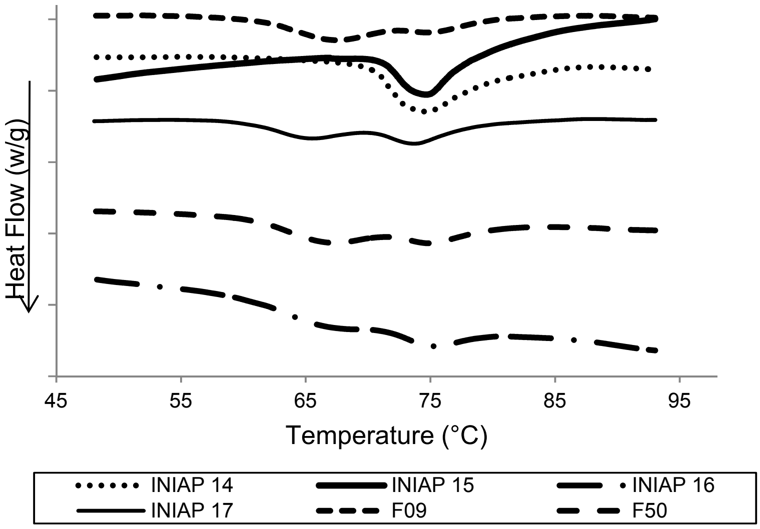

Heat Flow (w/g)
45
55
65
75
85
95
Temperature (°C)
INIAP 14
INIAP 15
INIAP 16
INIAP 17
F09
F50

Figure 3.