Accepted Manuscript

Optimization of rice bread formulation by mixture design and relationship of bread quality to flour and dough attributes

Jennifer Elizabeth Cajas Locke, Luciana Carla González, Maria Ana Loubes, Marcela Patricia Tolaba

PII: S0023-6438(19)30639-5
DOI: https://doi.org/10.1016/j.lwt.2019.108299
Article Number: 108299
Reference: YFSTL 108299

To appear in: *LWT - Food Science and Technology*

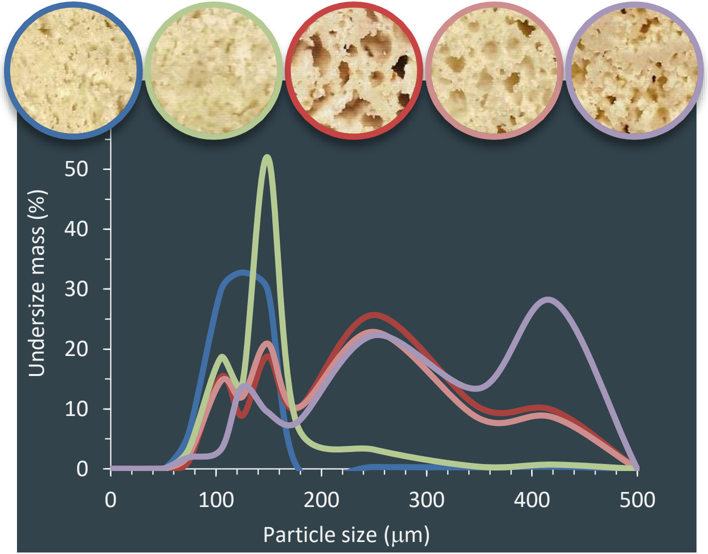
Received Date: 15 February 2019
Revised Date: 30 May 2019
Accepted Date: 21 June 2019

Please cite this article as: Cajas Locke, J.E., González, L.C., Loubes, M.A., Tolaba, M.P., Optimization of rice bread formulation by mixture design and relationship of bread quality to flour and dough attributes, *LWT - Food Science and Technology* (2019), doi: https://doi.org/10.1016/j.lwt.2019.108299.

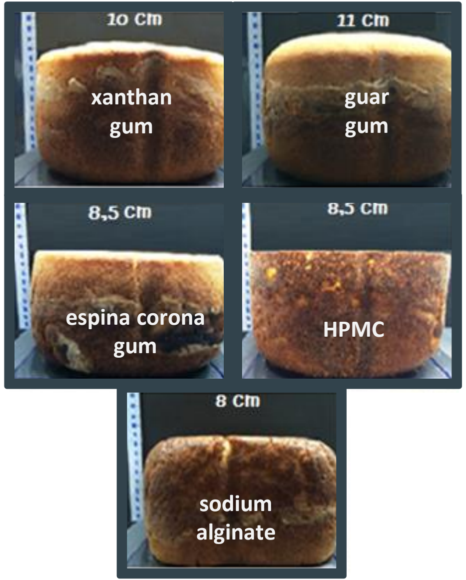
This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Gluten-free bread

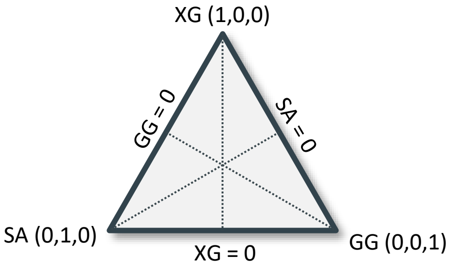
Rice flour selection



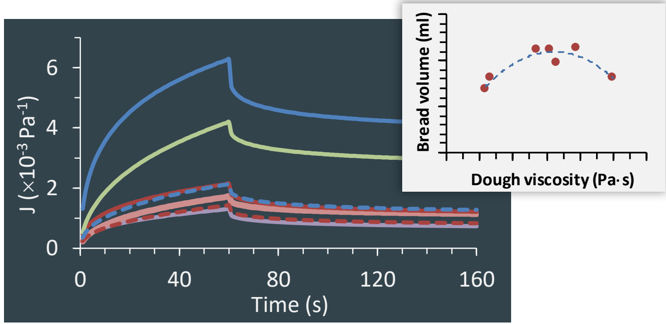
Gluten substitutes selection



Mixture design



Dough rheology



ACCEPTED MANUSCRIPT

Optimization of rice bread formulation by mixture design and relationship of bread quality to flour and dough attributes

Jennifer Elizabeth Cajas Locke [1,2], Luciana Carla González [1,2], Maria Ana Loubes [1,2],
Marcela Patricia Tolaba [1,2,] *

[1] University of Buenos Aires, School of Exact and Natural Sciences, Department of Industries, Buenos Aires, Argentina.

[2] CONICET - University of Buenos Aires, Institute of Food Technology and Chemical Processes (ITAPROQ), Buenos Aires, Argentina.

*Corresponding author. Address: Facultad de Ciencias Exactas y Naturales - Universidad de Buenos Aires - Intendente Güiraldes 2160 - Ciudad Universitaria - C1428EGA - Ciudad Autónoma de Buenos Aires - Argentina; Phone/ Fax: 54 11 4576 3366; mtolaba@di.fcen.uba.ar[1]

Abbreviations

GS: gluten substitutes, XG: xanthan gum, GG: guar gum, SA: sodium alginate, HPMC: hydroxypropyl methylcellulose, ECG: espina corona gum, SM: Santa María flour, K: Kapac flour, SP: Señor de Sipan flour, PG: partially gelatinized flour, TG: totally gelatinized flour, D50: median diameter, DI: dispersion index, ΔH: gelatinization enthalpy, WAI: water absorption index, WSI: water solubility index, SWP: swelling power, BV: bread volume, CAF: cell area fraction, MCA: mean cell area, CD: cell density, TPA: texture profile analysis, LVR: linear viscoelastic region.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

Abstract

The bread making aptitude of five rice flours (native and gelatinized) and five gluten substitutes (GS) were prior tested and the best ingredients for mixture design were set. Native flour with a wide distribution of particle size, xanthan gum (XG), guar gum (GG) and sodium alginate (SA) were selected due to their good performance. The effect of formulation on bread volume (BV), cell area fraction (CAF) of breadcrumb and dough rheology was determined by using a simplex centroid mixture design with constrain (2.1 g of GS/100 g of flour). A significant effect of formulation on viscoelasticity of dough was observed. A non-linear relationship between BV and dough viscosity was found with maximum BV at 60000 Pa·s. The optimum formulation, from XG to GG mass ratio of 0.71, yields maximum values of BV (4.07 ml/g of flour) and CAF (29%); optimum bread presented good textural attributes and a slightly toasted crust.

Keywords: gluten substitute, image analysis, gas cells, baking quality

1. Introduction

The increasing demand of gluten free food has favored the development of rice-based products. Rice is preferred by its hypoallergenic character, high content of easily digestible carbohydrates and low sodium and prolamin contents (Gujral & Rosell, 2004).

In contrast with wheat bread, rice bread production requires the addition of hydrocolloids with ability to form viscoelastic dough to emulate the gluten functionality (Kohlwey, Kendall, & Mohindra, 1995). Hydrocolloids contribute with gas retention during fermentation and cooking, playing a key role to set dough structure and bread texture.

Gluten has been replaced by gums, hydrocolloids (agar; CMC; HPMC; among others) and enzymes such as amylases, proteases or hemicellulases (Molina-Rosell, 2013; Gujral & Rosell, 2004). For rice bread, XG and HPMC have been proposed as GS because of their beneficial effect on BV although its use makes the product more expensive (Rosell & Marco, 2008).

Mixture design is frequently applied to optimize bread formulation (Yilmaz, Yildiz, Yurt, Toker, & Baştürk, 2015). The influence of flour particle size, on rice bread quality (de la Hera, Martinez, & Gómez, 2013; Sánchez, González, Osella, Torres, & de la Torre, 2008) as well as the effect of bread formulation on bread quality and dough rheology (Tao, Xiao, Wu, & Xu, 2018; Witczak, Korus, Ziobro, & Juszczak, 2019) have been studied. Oscillatory tests such as creep-recovery essays have been successfully applied to investigate the rheological behavior of dough and its relationship with quality attributes of bread. However, the information concerning to the viscoelastic properties of gluten free dough and the correlations between bread quality and rheological parameters is quite limited (Lazaridou, Duta, Papageorgiou, Belc, & Biliaderis, 2007).

Several studies of gluten free bread using combinations of corn, rice, buckwheat or Andean cereals flours have been published (Hager & Arendt, 2013; Machado Alencar, Steel, Alvim, de Morais & Bolini, 2015). However, the present study is focused on rice based bread from Argentinean rice varieties. Several local rice flours were evaluated in order to select the most suitable one.

The aim of the present work was first to evaluate the bread making aptitude of five rice flours (native and gelatinized) and five GS in order to select the best ingredients (flour and three GS) for mixture design. BV and quality of breadcrumb were evaluated. In a

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

second step the effect of the ratio of three GS on BV, CAF, cell density and viscoelastic behavior of dough were determined by means of simplex centroid mixture design with constrain (2.1 g of GS/100 g of flour). Bread crust color, moisture content and texture profile analysis (TPA) of breadcrumb were measured to characterize the optimal bread. Relationship among viscoelastic parameters of dough and bread quality was also investigated.

2. Materials and methods

2.1. Materials

Three Argentinean commercial rice flours were tested: SM flour (Santa María, Ana Hernández Productos Alimenticios SRL), K flour (Kapac, Alimentos Específicos S.A.) and SP flour (Señor de Sipan, Productos libres de gluten SRL). Partially gelatinized flour (PG) was obtained by high impact milling (Loubes & Tolaba, 2014). Parboiled rice (Molinos Río de la Plata, Argentina) was milling 1 min using a knife mill to obtain totally gelatinized flour (TG). Table 1 summarizes the proximate composition of flours (AOAC, 2000) including amylose content (Morrison & Laignelet, 1983).

SA and HPMC (Sigma-Aldrich, USA), XG and GG (Doña Clara, Argentina), espina corona gum (Ideasupply Argentina S.A., Argentina) were used as GS. Bread ingredients (cassava starch, milk powder, egg powder, salt, sugar, dry yeast, sunflower oil) were purchased at a local market (Doña Clara, Argentina).

2.2. Flour characterization

ACCEPTED MANUSCRIPT

Flour sample (200 g) was sieved through a set of sieves (ASTM Nº: 35, 40, 45, 60, 80, 100, 120, 140, 200, 270, 325, ASTM Standard, USA). Median diameter (D50) and dispersion index (DI=(D90-D10)/D50) based on mass fractions were reported.

Gelatinization temperature and enthalpy (ΔH) were measured in a calorimeter (DSC 822 Mettler Toledo, Switzerland) following the procedure of Loubes & Tolaba (2014). Hydration properties were determined at 30°C: WAI (water absorption index) by the method of Chiang & Yeh (2002), SWP (swelling power) and WSI (water solubility index) following the procedure of Loubes & Tolaba (2014). All reported values were the average from three replicates.

2.3. Bread making

Bread formulation involved: rice flour (384 g), cassava starch (16 g), milk powder (84 g), sugar (12 g), egg powder (10 g), salt (8 g), dry yeast (8 g), GS (8 g), bi-distilled water (448 g) and sunflower oil (40 ml). Production steps using an electric bread oven (ATMA HP 4040, Argentina) were: mixing (31 rpm, 25 min), fermentation (25 °C-20 min, 32 °C-25 min and 38 °C-45 min) and cooking (121 °C-65 min). Bread was then cooled (60 min, room temperature) and stored (4°C) in plastic bags until further analysis.

2.4. Bread quality

BV was determined by seed displacement (Sánchez et al., 2008). Breadcrumble quality was set by image analysis (Pongjaruvat Methacanon, Seetapan, Fuongfuchat, & Gamonpilas, 2014). Digital images acquired with a multifunction printer (HP PSC

ACCEPTED MANUSCRIPT

1610, Brazil) were analyzed by using ImageJ software (v. 1.42q, National Institutes of Health, USA). The average values of BV, cell area fraction (CAF), mean cell area (MCA) and cell density (CD) from at least five replicates were reported.

2.5. Mixture design

A simplex centroid design with constrain was applied to analyze the effect GS (2.1 g of GS/100 g of flour) on bread attributes. Each response (Y), was modeled as function of codified factors (x_i, x_j, x_k) by means of the equation (Scheffé, 1958):

$$Y = \sum_{i=1}^{3} \beta_i x_i + \sum \sum_{i<j}^{3} \beta_{ij} x_i x_j + \sum \sum \sum_{i<j<k}^{3} \beta_{ijk} x_i x_j x_k \qquad (1)$$

where β_i represents the effect of each component, β_{ij} and β_{ijk} the interaction effects between components *i* and *j* and *k*. A linear relationship between the amount of GS and each coded factor was adopted.

2.6. Dough rheology

Oscillatory tests were performed at 25°C by duplicate in a controlled-stress rheometer Paar Physica, model MCR 300 (Anton Paar, Graz, Austria) which is provided with two parallel plates (3 cm of diameter, gap = 1 cm) and a Peltier cell. Dough sample (10 g), without yeast, was placed between the plates, then the edges of the sample were sealed using silicone oil (viscosity: 290-310 mPa·s).

ACCEPTED MANUSCRIPT

Linear viscoelastic region (LVR) was set from deformation sweep (0.1-100%) at constant frequency (1 Hz). Frequency sweep (1-100 Hz) was performed at 1% deformation within LVR. Viscoelastic modulus (G´ and G", Pa) and damping factor (tan $\delta = G''/G'$) were recorded as function of frequency. Creep-recovery test involved a first step at constant stress (10 Pa) within the LVR during 60 s to complete the creep stage. Then the stress was removed and the recovery step began and continued for 100 s while the compliance (J, Pa^{-1}) was recorded as function of time (t). J was modeled during creep (Eq. 2) and recovery (Eq. 3) phases by Burger's model (Burger, 1935):

$$J_c\ (t) = J_0 + J_m\ [1 - \exp(-t/\lambda)] + t/\mu_0 \qquad (2)$$

$$J_r\ (t) = J_{max} - J_0 - J_m\ [1 - \exp(-t/\lambda)] \qquad (3)$$

Where J_c and J_r are compliances during creep and recovery, respectively; J_0, J_m and J_{max} represent the instantaneous, viscoelastic, and maximum creep compliance, respectively; λ is the retardation time and μ_0 is the steady state viscosity.

2.7. Optimal bread characterization

Bread crust color was measured with a Minolta photo-colorimeter (Minolta CM-508d, Tokyo, Japan) using the D illuminant. CIE L*a*b* and CIE L*C*h coordinates were measurements in eight random positions and their average value were reported. Moisture content of breadcrumb was determined by triplicate using 44-15 AACC method (AACC, 2000). TPA of breadcrumb was performed in a universal texture machine (Instron 3345, USA). A cylinder of breadcrumb (diameter: 30 mm; thickness: 20 mm) was compressed at 1 mm/s up to 50% using a cylindrical probe (diameter: 3.5

ACCEPTED MANUSCRIPT

mm). After 10 s the procedure was repeated. Hardness, adhesiveness, cohesiveness and elasticity were obtained through the device’s software and the average of 25 replicates was reported.

2.8. Statistical analysis

Statistical analyses of single ANOVA and Fisher test (LSD) were performed with a confidence level of 95%. Multivariate analysis (Pearson´s matrix) was applied to detect correlations between product attributes. Statistical tests and mixture design were made by using Statgraphics software Centurion version XVI (Statistical graphics Corporation, USA).

3. Results and Discussion

3.1. Flour properties

Particle size, gelatinization and hydration properties are shown in Table 2. Particle size of K and SP flours were similar with peaks at 105 µm, 150 µm, 250 µm and 420 µm (data in Supplementary Material 1). Gelatinized flour (TG) presented peaks at 250 µm, 420 µm, and 125 µm. In contrast, flour SM presented a mono modal distribution (peak at 125 µm) while PG flour had a bimodal distribution (peaks at 149 µm and 53 µm). SM and PG presented lower granulometry and DI in comparison with the others. As the particle size distribution strongly influences the behavior of dough and sets the bread quality (Sánchez et al., 2008), these evaluations are relevant, and they showed the diversity of rice flour granulometry in the local market.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

In accordance with the study of Iturriaga, Lopez, & Añon (2004) for long grain rice varieties cultivated in Argentina, peak temperatures between 65 °C and 69 °C were here obtained. Different gelatinization degrees were observed: 78% (PG), 100% (TG) and 0% (SM, SP, K). Gelatinized flours showed higher values of hydration properties in comparison with native flours (Table 2). Particularly, PG doubled the values of SWP respect to K and SP native flours. In general, hydration increased as particle size decreased; a similar correspondence was also observed by de la Hera et al. (2013).

It must be noted that significant correlations were found: D50-WAI ($r = -0.70$, $p < 0.05$), D50-WSI ($r = -0.82$, $p < 0.01$), WAI-ΔH ($r = -0.83$, $p < 0.01$) and WSI-ΔH ($r = -0.68$, $p < 0.05$). These results evidenced an increase of WAI and WSI as well as a decrease of ΔH with decreasing values of D50. In other words, rice flours with fine granulometry exhibit pre-gelatinized character, high hydration capacity and high solubility.

3.2. Flour selection

The selection was based on the effect of flour particle size on bread quality. The aim was to maximize BV and CAF. Breads were made with XG (procedure in section 2.3). The highest volume was obtained with K flour (1304 ± 48 ml) followed by SP flour (1332 ± 67 ml). BV of 1098 ± 55 ml (SM flour) and 1037 ± 52 ml (PG flour) were obtained while TG flour produced the lowest BV (unacceptable). A significant correlation BV-DI ($r = 0.98$; $p < 0.05$) was found; high values of DI favored BV. The same conclusion was also obtained by Sánchez, González, Osella, Torres, & de la Torre, (1999) and Martínez (2012) who produced rice-based bread.

ACCEPTED MANUSCRIPT

Bread slices used to determine CAF by image analysis are shown in Fig. 1. K flour exhibited the highest CAF (26 ± 1.5%) followed by SP (19.4 ± 1.5%), SM (8.1 ± 0.4%) and PG (8.1 ± 1.3%). A significant correlation D50-CAF ($r = 0.95$, $p < 0.05$) was found. As K flour (DI=1.37 and a multimodal particle size distribution: 105-420 μm) provided the best performance, it was selected for the optimization of bread formulation (section 3.4).

3.3. Selection of gluten substitutes

The effects of GS on BV and breadcrumb quality were determined (Table 3). Breads were made with K flour and a fixed amount (8 g) of each GS (section 2.3).

GG produced the highest volume followed by XG. The difference between them can be attributed to the higher dough viscosity obtained with XG, due to its molecular structure and higher molecular weight (2000 kDa). XG is a polysaccharide containing d-glucose, d-mannose, and d-glucuronic acid as building blocks in a molecular ratio of 3:3:2 with a high number of trisaccharide side chains. On the other hand, GG is a galactomannan with a lower molecular weight of 300 kDa, it has a mannose backbone with galactose side chains (mannose to galactose molar ratio of 1.8). Breads elaborated with SA or HPMC presented, in contrast, the lowest BV.

XG produced the highest CAF followed by SA and GG. Particularly, SA produced the highest mean CA (1.63 mm^2/cell) with a CD similar to that of GG. The presence of gas cell uniformly distributed has been associated to the structure stability after shaking, which could be favored by a high viscosity of the mixture (Hager & Arendt, 2013). XG and GG provided good volume while SA produced well-sized cell. Therefore, they were chosen to optimize bread formulations (section 3.4).

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

3.4. Bread formulations

The effects of bread formulation (based on K flour, XG, GG and SA), on bread attributes were determined (Table 4). The combination of gums presented the highest BV but similar values were also obtained with XG-GG-SA and XG-SA formulations. In contrast, SA provoked a significant reduction ($p < 0.05$) in BV (28%) in comparison with XG-GG combination. The specific volume of bread here obtained (1.3-1.8 ml/g) was lower than that reported (3.6-4.3 ml/g) by Aoki, Umemoto, Okamoto, Suzuki, & Tanaka, (2015), who used twice the amount of GS in comparison with the present work. All bread slices presented an acceptable appearance (Figure 2). Wide ranges of CD (6.8-21.7 cells/cm^2), MCA (1.2-2.79 mm^2/cell) and CAF (18.4-29.7%) were obtained (Table 4). XG produced, in comparison with others substitutes, higher CD which means a more compact breadcrumb (Fig. 2). In contrast, XG-GG mixture and ternary mixture provided the highest values of MCA favoring a greater porosity of breadcrumb (Fig. 2). The CD obtained with GG was similar to that informed by Ziobro, Korus, Witczak, & Juszczak (2012) for bread based on corn and potato starches. CD here obtained were lower than those reported (42-61 cells/cm^2) by Machado et al. (2015) for rice bread enriched with 20% of quinoa or amaranth flour. The interaction between mixture components is enhanced by adding a protein flour obtaining a more compact porosity.

3.5. Mixture design analysis

The effect of GS on BV and CAF was satisfactorily simulated by means of Eq. 1. All GS had significant effects ($p < 0.05$) on bread quality; the interaction effect between gums was significant. A quadratic model was adequate ($R^2 = 0.945$) to simulate BV as

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

function of GS (Fig. 3.a) while a cubic expression was required to satisfactorily (R^2 = 0.997) model CAF (Fig. 3.b). A synergic effect among gums in the absence of SA was detected from the optimization analysis. Maximum values of BV (1645 ml) and CAF (30.1%) were obtained by using XG to GG mass ratios of 0.71 and 1.7, respectively. In contrast, the lowest BV (1169 ml) was obtained in the absence of gums, with the maximum concentration of SA. Synergistic interaction between polysaccharides has been attributed to cross linking capacity of polymer's chains, which has a favorable impact on textural properties of bread (Wang, Wang, & Sun, 2002). The synergistic effect among gums has been explained based on the interaction of the exposed mannose segments in the backbone of the guar gum macromolecule with single-helical portions of xanthan molecules to form a complex which yield a three-dimensional network and gel.

Bread quality obtained in the present work is comparable to that informed by Lazaridou et al. (2007), who used a combination of several functional ingredients (XG, pectin, agarose, β-glucan, CMC) to reach good BV and texture in rice bread.

Multiple optimization analysis was also performed to maximize BV and CAF simultaneously. It was found a desirability of 0.95 for XG to GG mass ratios of 0.713 (without SA). To validate the model, bread was elaborated with this optimum mixture obtaining 1563 ml of BV and 29% of CAF, in accordance with the predicted values (Eq. 1).

3.5.1. Characterization of optimum bread

Optimum bread presented a slight toasted crust (L*: 24.53 ± 0.78; a*: 17.72 ± 0.25; b*: 25.51 ± 0.71) and a breadcrumb with a moisture content of 53.25 ± 1.04% (db).

ACCEPTED MANUSCRIPT

Browning of bread crust, produced by Maillard reaction and influenced by the presence of reducing sugars and amino acids (Kent & Evers, 1994), is a desirable attribute in rice breads which present higher luminosity in comparison with wheat breads (Gallagher & Gormley, 2002). Optimum bread had values of chroma (C* = 31.07 ± 0.69), hue (h = 55.16 ± 0.51) and moisture content similar to those reported in the literature for gluten free breads (Martínez, 2012; Ronda, Perez-Quirce, Lazaridou, & Biliaderis, 2015).

Hardness (20.96 ± 0.85 N), elasticity (0.81 ± 0.01), cohesiveness (0.29 ± 0.01), gumminess (6.01 ± 0.28), chewiness (4.89 ± 0.24) and adhesiveness (not detected) of the optimal bread, reflect a good quality bread considering literature reports (Ronda et al., 2015; Machado et al., 2015; Ziobro et al., 2012).

3.6. Rheological behavior of dough

3.6.1. Frequency sweep tests

LVR was prior tested. XG presented a more extended LVR (0.1 to 8.3%) in comparison with GG (1-5.2%) or SA (1-4.7%). The highest LVR were obtained for binary (0.1-8.0%) and ternary (1-17.8%) mixtures due to synergic effect among GS. These results were similar to those reported by Lazaridou et al. (2007) and Sivaramakrishnan, Senge, & Chattopadhyay (2004) for dough to make gluten-free bread.

Frequency sweep is shown in Fig. 4. G´ was independent of frequency within 1 to 50 Hz. All mechanical spectra revealed that the elastic character (G’ > G”) prevails up to a frequency value which was dependent of bread formulation. For XG and GG it was up to 70 Hz while for XG-GG was up to 92 Hz. These results are in accordance with literature reports (Sivaramakrishnan et al., 2004; Gujral & Rosell, 2004). SA produced

ACCEPTED MANUSCRIPT

in contrast a viscous character from 26 Hz with a significant reduction of viscoelastic modulus (788 Pa), at tan δ = 1, in comparison with those of gums (G’ = G” = 6840-8890 Pa). The distinctive rheological behavior of different formulations reflects the specific interactions rice flour-GS and GS-GS. As regard the interactions between hydrocolloids, it must be mentioned the synergic effect among XG and GG (which was previously explained) and the ternary interaction between SA and the complex formed by GG and XG. Harding, Smith, Lawson, Gahler, & Wood (2011) who studied the macromolecular interactions in ternary mixtures of hydrocolloids, have hypothesized that a complex of two polysaccharides was required to promote non-covalent interactions between SA and the complex of gums.

3.6.2. Creep-recovery tests

The significant effect of bread formulation on creep-recovery tests and the viscoelastic character of dough can be appreciated in Fig. 5. XG showed the highest resistance to deformation followed by XG-GG. In contrast, SA and SA-GG produced the maximum values of dough strain and residual deformation at the end of creep and recovery phases. Residual deformation reflects the magnitude of the viscous component. High values are associated to low capacity of gas retention and its unfavorable effect on BV (Table 4). XG due to its rigid, ordered chain conformation, shows high viscosity values at low shear rates favoring dough elasticity and the increase of BV (Lazaridou et al., 2007). Compliance was satisfactorily simulated ($R^2 > 0.99$) by Burger’s model (Eq. 2 and 3). As shows in Table 5, all compliance values in creep phase (J_0, J_m) were higher in comparison with those of XG while viscosities (μ_0) were lower than that of XG. These results were comparable to those reported by Lazaridou et al. (2007) for dough to

ACCEPTED MANUSCRIPT

produce gluten-free bread. Dough involved in pasta production shows in contrast lower values of compliances (Sozer, 2009). This is due to the higher value of shear stress (~ 750 Pa) applied in pasta evaluation in comparison with the present work (10 Pa).

For creep phase the relative contributions of instantaneous compliance ($J_0/(J_0+J_m)$) and average compliance ($J_m/(J_{0+} J_m)$) were within 16-29% and 71-84% respectively. Values of mean retardation time (λ) were, in general, slightly higher than that of XG formulation. The differences in the viscoelastic behavior can be interpreted in terms of the differences in the stretching of the associative network, which is set by non-covalent intermolecular bonds between starch and GS (Edwards, Peressini, Dexter, & Mulvaney, 2001). For recovery phase, the relative elastic contribution ($(J_0+J_m)/J_{max}$) was maximum for XG formulation (43.4%) while for GG-SA formulation was minimum (30.1%). Viscous character prevailed at the end of recovery phase for all samples tested. In addition, the retardation times increased significantly (between 18.3 s and 21.9 s) in comparison with those of the creep phase, due to the molecular stretching to which the components of the mixture are subjected during creep. An increase of retardation time during recovery phase, but of smaller magnitude (7 s), was also observed by Hernández-Estrada, Rayas-Duarte, Figueroa, & Morales-Sánchez (2014) in wheat-based dough. The influence of GS is related to its molecular structure and the conformation of the polysaccharide chains, which determine the possible cross-linking between polymer chains and mixture components.

Among all the substitutes studied, the XG exhibits the lowest compliance (J_m) and the highest steady state viscosity (μ_0). Viscoelastic behavior of dough from XG formulation is explained by the well-known ability of this gum to form a weak gel, as well as to provide high viscosity at low shear rate, due to the rigid conformation of its chains (Doublier & Cuvelier, 1996).

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

3.7. Relationship between dough and bread attributes

The non-linear relationship between BV and dough viscosity (Fig. 6) was satisfactorily simulated ($R^2 = 0.87$) by a quadratic equation. BV increased with the increase of dough viscosity up to 60000 Pa.s (critical value); a further increase of viscosity had a negative effect on volume. Gas retention capacity of dough was optimum at critical viscosity, favoring the production of high values of CD and MCA during baking. Similar relationship BV - dough viscosity were found by Ronda et al. (2015) who elaborated gluten free rice bread with the addition of β-glucans from oat and barley. The relationship here presented can be useful to predict the aptitude of dough to produce good quality bread.

4. Conclusions

The effect of flour granulometry on bread quality was significant. Multimodal particle size distribution and high dispersion index led to good values of bread volume and gas cells. Due to its positive effect on bread quality: XG, GG and SA were selected to perform the mixture design. A differentiated viscoelastic behavior of dough could be observed from different formulations. Rheological tests evidenced the synergic effects between gums. SA produced low gas retention capacity of dough. In contrast, dough samples elaborated with xanthan gum or combination of gums showed the highest volume and dough resistance. The rheological behavior during creep-recovery test was satisfactorily modeled by Burger’s model. The steady state viscosity of dough was

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

related to bread quality. Maximum bread volume was obtained from dough with 60000 Pa·s of viscosity.

Bread formulation was satisfactorily optimized by mixture design. Bread volume and CAF were significantly enhanced by addition of guar gum and xanthan gum to the formulation. Optimum bread presented desirable attributes in terms of crust color, texture profile and moisture content of the breadcrumb.

5. Acknowledgments

The authors acknowledge the financial support from Buenos Aires University and National Council of Scientific Research of Argentina. This work has been funded by PME-2006-01685 and UBACYT (Project UBACYT 20020170100367BA).

6. References

AACC (2000). *Approved methods of the American Association of Cereal Chemists* (10th ed.). St Paul, Minnesota: American Association of Cereal Chemists.

Association of Official Analytical Chemists (AOAC). (1995). *Official methods of analysis* (16th ed.). Washington, D.C: Association of Official Analytical Chemists.

Aoki, N., Umemoto, T., Okamoto, K., Suzuki, Y., & Tanaka, J. (2015). Mutants that have shorter amylopectin chains are promising materials for slow-hardening rice bread. *Journal of Cereal Science*, 61, 105-110.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

Burger, J. M. (1935). *First report on viscosity and plasticity*. Nueva York: Nordemann publishing company.

Chiang, P.Y., & Yeh, A.I. (2002). Effect of Soaking on Wet-milling of Rice. *Journal of Cereal Science*, 35, 85-94.

Cornejo, F., & Rosell, C.M. (2015). Physicochemical properties of long rice grain varieties in relation to gluten free bread quality. *LWT - Food Science and Technology*, 62, 1203-1210.

De la Hera, E., Martinez, M., & Gómez, M. (2013). Influence of flour particle size on quality of gluten-free rice bread. *LWT - Food Science and Technology*, 54(1), 199-206.

Doublier, J.L., & Cuvelier, G. (1996). Gums and Hydrocolloids: Functional Aspects. In A.C., Eliasson (Ed), *Carbohydrates in Food* (pp. 283-318). New York: Marcel Dekker Inc.

Edwards, N.M., Peressini, D., Dexter, J.E., & Mulvaney, S.J. (2001). Viscoelastic properties of durum wheat and common wheat dough of different strengths. *Rheologica Acta*, 40, 142-153.

Gallagher, E., & Gormley, T.R. (2002). *The quality of gluten free breads produced at retail outlets*. Research Report. Dublin: Teagasc, The National Food Center.

ACCEPTED MANUSCRIPT

Gujral, H.S., & Rosell, C.M. (2004). Improvement of the breadmaking quality of rice flour by glucose oxidase. *Food Research International*, 37, 75-81.

Hager, A.S., & Arendt, E.K. (2013). Influence of hydroxypropylmethylcellulose (HPMC), xanthan gum and their combination on loaf specific volume, crumb hardness and crumb grain characteristics of gluten-free breads based on rice, maize, teff and buckwheat. *Food Hydrocolloids*, 32(1), 195-203.

Harding, S.E., Smith, I.H. Lawson, C.J., Gahler, R.J., & Wood, S. (2011). Studies on macromolecular interactions in ternary mixtures of konjac glucomannan, xanthan gum and sodium alginate. *Carbohydrate Polymers*, 83(2), 329-338.

Hernández-Estrada, Z.J., Rayas-Duarte, P., Figueroa, J.D.C., & Morales-Sánchez, E. (2014). Creep recovery tests to measure the effects of wheat glutenins on doughs and the relationships to rheological and breadmaking properties. *Journal of Food Engineering*, 143, 62-68.

Iturriaga, L., Lopez, B., & Añon, M. (2004). Thermal and physicochemical characterization of seven argentine rice flours and starches. *Food Research International*, 37(5), 439-447.

Kent, N.L., & Evers, A.D. (1994). Bread made with gluten substitutes. *Technology of cereals*, 215.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

Kohlwey, D.E., Kendall, J.H., & Mohindra, R.B. (1995). Using the physical properties of rice as a guide to formulation. *Cereal Food World*, 40(10), 728-732.

Lazaridou, A., Duta, D., Papageorgiou, M., Belc, N., & Biliaderis, C.G. (2007). Effects of hydrocolloids on dough rheology and bread quality parameters in gluten-free formulations. *Journal of Food Engineering*, 79, 1033-1047.

Loubes, M.A., & Tolaba, M.P. (2014). Thermo-mechanical rice flour modification by planetary ball milling. *LWT - Food Science and Technology*, 57(1), 320-328.

Machado Alencar, N.M., Steel, C.J., Alvim, I.D., de Morais, E.C., & Bolini, H.M.A. (2015). Addition of quinoa and amaranth flour in gluten-free breads: Temporal profile and instrumental analysis. *LWT - Food Science and Technology*, 62(2), 1011-1018.

Magaña, E.M., Ramírez, B., Torres, P.I., Sánchez, D.I., & López, J. (2011). Efecto del contenido de proteína, grasa y levadura en las propiedades viscoelásticas de la masa y la calidad de pan tipo francés. *Ciencia y tecnología de América o Interciencia*, 36(4), 248-255.

Martínez, M. (2012). *Influencia de la adición de harinas extruídas en la elaboración de panes de arroz* (Master’s Thesis). Universidad de Valladolid, Soria, España.

Molina-Rosell, C. (2013). Alimentos sin gluten derivados de cereales. In L., Rodrigo, A.S., Peña (Eds.), *Enfermedad celíaca y sensibilidad al gluten no celíaca* (pp. 447-461). España: Omnia Publisher.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

Morrison, W.R., & Laignelet, B. (1983). An improved colorimetric procedure for determining apparent and total amylose in cereal and other starches. *Journal of Cereal Science*, 1, 9-20.

Pongjaruvat, W., Methacanon, P., Seetapan, N., Fuongfuchat, A., & Gamonpilas, C. (2014). Influence of pregelatinized tapioca starch and transglutaminase on dough rheology and quality of gluten-free jasmine rice breads. *Food Hydrocolloids,* 36, 143-150.

Ronda, F., Perez-Quirce, S., Lazaridou, A., & Biliaderis, C. (2015). Effect of barley and oat β-glucan concentrates on gluten-free ricebased doughs and bread characteristics. *Food Hydrocolloids*, 48, 197-207.

Rosell, M., & Marco, C. (2008). Rice. In E.K., Arendt, F., Dal Bello (Eds.), *Gluten - Free Cereal Products and Beverages* (pp. 81-96). Cambridge: Academic Press.

Sánchez, H.D., González, R.J., Osella, C.A., Torres, R.L., & de la Torre, M.A.G. (1999). Comportamiento de variedades de arroz en la elaboración de pan sin gluten. *Archivos Latinoamericanos de Nutrición*, 49(1), 162-165.

Sánchez, H.D., González, R.J., Osella, C.A., Torres, R.L., & de la Torre, M.A.G. (2008). Elaboración de pan sin gluten con harinas de arroz extrudidas. *Ciencia y Tecnología Alimentaria*, 6(2), 109-116.

ACCEPTED MANUSCRIPT

Scheffé, H. (1958). Experiments with mixtures. *Journal of the Royal Statistical Society B*, 20, 344-360.

Sivaramakrishnan, H.P., Senge, B., & Chattopadhyay, P.K. (2004). Rheological properties of rice dough for making rice bread. *Journal of Food Engineering*, 62, 37-45.

Sozer, N. (2009). Rheological properties of rice pasta dough supplemented with proteins and gums. *Food Hydrocolloids*, 23, 849-855.

Yilmaz, M.T., Yildiz, Ö., Yurt, B., Toker, O.S., & Baştürk, A. (2015). A mixture design study to determine interaction effects of wheat, buckwheat, and rice flours in an aqueous model system. *LWT - Food Science and Technology*, 61(2), 583-589.

Tao, H., Xiao, Y., Wu, F., & Xu, X. (2018). Optimization of additives and their combination to improve the quality of refrigerated dough. *LWT - Food Science and Technology*, 89, 482-488.

Wang, F., Wang, Y.J., & Sun, Z. (2002). Conformational role of xanthan gum in its interaction with guar gum. *Food Chemistry and Toxicology*, 67(9), 3289-3294.

Witczak, M., Korus, J., Ziobro, R., & Juszczak, L. (2019). Waxy starch as dough component and anti-staling agent in gluten-free bread. *LWT - Food Science and Technology*, 99, 476-482.

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

Ziobro, R., Korus, J., Witczak, M., & Juszczak, L. (2012). Influence of modified starches on properties of gluten-free dough and bread. Part II: Quality and staling of gluten-free bread. *Food Hydrocolloids*, 29, 68-74.

ACCEPTED MANUSCRIPT

Figure captions

Fig. 1. Cross-section of pan breads made from different rice flours. SM: Santa María flour, K: Kapac flour, SP: Señor de Sipan flour, PG: Partially gelatinized flour.

Fig. 2. Cross-section of pan breads as function of mixture design. XG: xanthan gum, SA: sodium alginate, GG: guar gum.

Fig. 3. Predicted surfaces of bread quality as function of codified factors a) Bread volume (BV), b) Cell area fraction (CAF) of breadcrumb.

Fig. 4. a) Elastic modulus (G’) and b) damping factor (tan δ), of dough as function of bread formulation during frequency sweep at 25 °C with constant deformation of 1%. XG: xanthan gum (▲), SA: sodium alginate (☐), GG: guar gum (△), XG-GG (◆), XG-SA-GG (■), SA-GG (●), XG-SA (◇).

Fig. 5. Creep-recovery tests as function of bread formulation. XG: xanthan gum (—), SA: sodium alginate (—), GG: guar gum (—), XG-GG (- -), XG-SA-GG (- -), SA-GG (—), XG-SA (—).

Fig. 6. Relationship between bread volume (BV) and steady state viscosity of dough (μ_0).

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

Table 1

Proximate chemical composition of tested rice flours[1].

Composition (g/100 g, db)	**Flours**				
	SM	**K**	**SP**	**PG**	**TG**
Moisture	11.16 ± 0.09^{bc}	11.63 ± 0.11^{c}	11.12 ± 0.17^{b}	10.62 ± 0.03^{a}	12.13 ± 0.21^{d}
Carbohydrate	78.99 ± 1.07^{a}	79.80 ± 0.60^{a}	79.20 ± 0.84^{a}	79.5 ± 1.39^{a}	78.10 ± 0.82^{a}
Protein	5.92 ± 0.05^{b}	4.18 ± 0.08^{a}	6.89 ± 0.11^{c}	7.04 ± 0.09^{c}	7.22 ± 0.14^{c}
Lipid	1.18 ± 0.02^{c}	1.59 ± 0.02^{d}	0.32 ± 0.00^{b}	0.10 ± 0.00^{a}	0.10 ± 0.00^{a}
Fiber	2.37 ± 0.09^{d}	1.59 ± 0.03^{b}	0.53 ± 0.01^{a}	1.45 ± 0.04^{b}	2.06 ± 0.03^{c}
Ash	0.50 ± 0.00^{b}	1.21 ± 0.03^{c}	1.95 ± 0.05^{d}	1.29 ± 0.04^{c}	0.38 ± 0.01^{a}

[1] Amylose content was within 18 – 22 g/100 g, db (dry basis).

SM: Santa María flour, K: Kapac flour, SP: Señor de Sipan flour, PG: Partially gelatinized flour, TG: Totally gelatinized flour.

Values with different letters in the same row are significantly different ($p < 0.05$).

ACCEPTED MANUSCRIPT

Table 2

Characteristic parameters of particle size distribution, and thermal and hydration properties of tested rice flours.

Flours	**D50** (μm)	**DI**	**Tp** (°C)	**ΔH** (J/g, db)	**WAI** (g/g, db)	**WSI** (%)	**SWP** (g/g, db)
SM	135 ± 2^{a}	0.40 ± 0.03^{a}	64.8 ± 0.1^{a}	4.8 ± 0.2^{b}	2.99 ± 0.02^{c}	2.54 ± 0.04^{b}	3.42 ± 0.03^{b}
K	220 ± 22^{b}	1.37 ± 0.2^{bc}	67.6 ± 0.4^{b}	6.2 ± 0.3^{c}	2.43 ± 0.02^{a}	1.21 ± 0.05^{a}	2.89 ± 0.06^{a}
SP	177 ± 9^{a}	1.64 ± 0.07^{c}	66.4 ± 0.2^{b}	4.0 ± 0.1^{b}	2.52 ± 0.02^{b}	1.34 ± 0.03^{a}	2.72 ± 0.03^{a}
PG	156 ± 1^{a}	0.43 ± 0.02^{a}	69.4 ± 0.5^{c}	1.5 ± 0.3^{a}	3.39 ± 0.01^{d}	2.80 ± 0.04^{c}	4.62 ± 0.15^{c}
TG	313 ± 11^{c}	1.08 ± 0.06^{b}	n.d.	n.d.	4.39 ± 0.03^{e}	2.75 ± 0.02^{c}	5.42 ± 0.02^{d}

D50: Particle sizes corresponding to 50% cumulative undersize mass (median diameter), DI: Dispersion index, Tp: Peak gelatinization temperatures, ΔH: Gelatinization enthalpy, WAI: Water absorption index, WSI: Water solubility index, SWP: Swelling power.

SM: Santa María flour, K: Kapac flour, SP: Señor de Sipan flour, PG: Partially gelatinized flour, TG: Totally gelatinized flour.

n.d.: not detected.

Values with different letters in the same column are significantly different ($p < 0.05$).

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

Table 3

Effect of gluten substitute on bread quality.

Gluten substitute	**Bread volume** (ml)	**Cell area fraction** (%)	**Mean cell area** (mm^2/cell)	**Cell density** ($cells/cm^2$)
XG	1304 ± 48^{ab}	26.0 ± 1.5^{c}	1.20 ± 0.08^{a}	21.7 ± 2.1^{b}
GG	1474 ± 47^{b}	21.5 ± 2.7^{bc}	1.41 ± 0.07^{ab}	15.2 ± 0.6^{a}
SA	1173 ± 42^{a}	23.1 ± 0.1^{c}	1.63 ± 0.05^{b}	14.2 ± 0.5^{a}
ECG	1312 ± 49^{ab}	13.0 ± 0.7^{a}	1.17 ± 0.07^{a}	11.1 ± 1.1^{a}
HPMC	1294 ± 48^{a}	16.4 ± 0.4^{ab}	1.36 ± 0.09^{a}	12.1 ± 0.9^{a}

XG: Xanthan gum, GG: Guar gum, SA: Sodium alginate, ECG: Espina corona gum, HPMC: Hydroxypropyl methylcellulose.

Values with different letters in the same column are significantly different ($p < 0.05$).

ACCEPTED MANUSCRIPT

Table 4

Experimental design and bread quality as function of formulation.

Mixtures	**Gluten substitute** (g) **XG** (Coded^{1})	 **SA** (Coded^{1})	 **GG** (Coded^{1})	**Bread volume** (ml)	**Cell area fraction** (%)	**Mean cell area** (mm^{2}/cell)	**Cell density** (cells/cm^{2})
1	8 (1)	0 (0)	0 (0)	1304 ± 48^{ab}	26.0 ± 1.5^{bc}	1.20 ± 0.08^{a}	21.7 ± 2.1^{d}
2	0 (0)	0 (0)	8 (1)	1474 ± 47^{bc}	21.5 ± 2.7^{ab}	1.41 ± 0.07^{ab}	15.2 ± 0.6^{c}
3	0 (0)	8 (1)	0 (0)	1173 ± 42^{a}	23.1 ± 0.1^{ab}	1.63 ± 0.05^{b}	14.2 ± 0.5^{c}
4	4 (0.5)	0 (0)	4 (0.5)	1622 ± 81^{c}	29.7 ± 3.1^{c}	2.79 ± 0.23^{c}	10.3 ± 0.4^{b}
5*	2.67 (0.33)	2.67 (0.33)	2.67 (0.33)	1618 ± 81^{c}	18.4 ± 0.4^{a}	2.56 ± 0.06^{c}	6.8 ± 0.6^{a}
6	0 (0)	4 (0.5)	4 (0.5)	1315 ± 66^{ab}	18.9 ± 0.3^{a}	1.53 ± 0.19^{ab}	11.9 ± 0.8^{bc}
7	4 (0.5)	4 (0.5)	0 (0)	1615 ± 81^{c}	20.1 ± 1.1^{a}	1.55 ± 0.12^{ab}	12.7 ± 0.8^{bc}

[1] A linear relationship among experimental and coded factors was used.

[*] Central point of experimental design (triplicate).

XG: Xanthan gum; SA: Sodium alginate; GG: Guar gum.

Values with different letters in the same column are significantly different ($p < 0.05$).

ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

Table 5

Burger’s model parameters (equations 2-3) of doughs as function of formulation.

Mixtures	$\mathbf{J_0}$ (10^{-4} Pa^{-1})	$\mathbf{J_m}$ (10^{-4} Pa^{-1})	$\mathbf{\mu_0}$ (Pa·s)	$\mathbf{\lambda}$ (s)	$\mathbf{R^2}$
Creep phase					
1	2.02 ± 0.05^{bc}	4.92 ± 0.12^{ab}	99486 ± 1890^{e}	6.46 ± 0.12^{a}	0.9992
2	1.42 ± 0.10^{a}	6.67 ± 0.83^{a}	65896 ± 977^{c}	7.81 ± 0.09^{d}	0.9994
3	8.96 ± 0.37^{e}	28.48 ± 0.83^{d}	23601 ± 288^{a}	6.53 ± 0.03^{a}	0.9989
4	1.67 ± 0.00 ^{ab}	4.96 ± 0.07^{a}	78495 ± 481^{d}	6.98 ± 0.00^{bc}	0.9993
5*	2.42 ± 0.04^{c}	7.82 ± 0.23^{b}	54129 ± 1165^{b}	7.09 ± 0.06^{c}	0.9992
6	3.12 ± 0.13^{d}	16.18 ± 0.93^{c}	26482 ± 1060^{a}	7.90 ± 0.16^{d}	0.9994
7	3.37 ± 0.08^{d}	8.53 ± 0.1^{b}	62663 ± 1358^{c}	6.70 ± 0.05^{ab}	0.9991

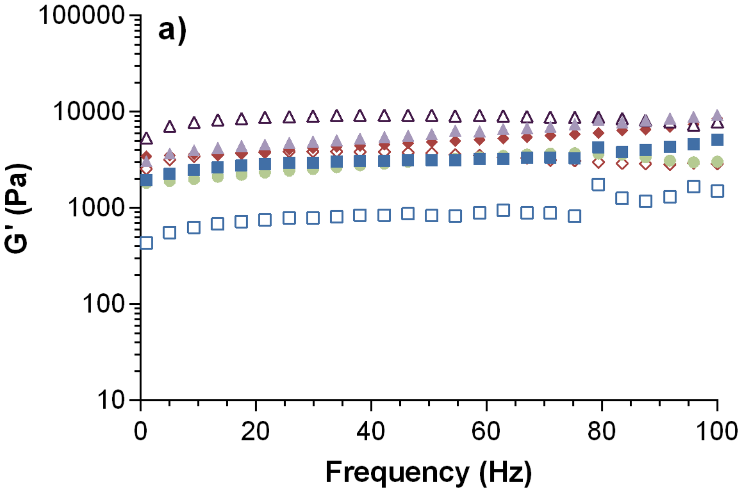
Mixtures	$\mathbf{J_0}$ (10^{-4} Pa^{-1})	$\mathbf{J_m}$ (10^{-4} Pa^{-1})	$\mathbf{J_{max}}$ (10^{-3} Pa^{-1})	$\mathbf{\lambda}$ (s)	$\mathbf{R^2}$
Recovery phase					
1	2.57 ± 0.06^{a}	2.95 ± 0.07^{a}	1.27 ± 0.03^{a}	26.49 ± 0.66^{a}	0.9929
2	2.21 ± 0.28^{a}	3.39 ± 0.44^{a}	1.69 ± 0.28^{ab}	26.12 ± 0.02^{a}	0.9931
3	10.78 ± 0.25^{e}	10.40 ± 0.24^{d}	6.17 ± 0.15^{d}	25.79 ± 0.13^{a}	0.9907
4	2.57 ± 0.01^{a}	3.23 ± 0.02^{a}	1.40 ± 0.01^{a}	25.72 ± 0.60^{a}	0.9923
5*	3.63 ± 0.04^{b}	4.74 ± 0.23^{b}	2.09 ± 0.05^{b}	26.15 ± 0.32^{a}	0.9931
6	5.00 ± 0.17^{d}	7.38 ± 0.49^{c}	4.11 ± 0.2^{c}	27.28 ± 0.23^{a}	0.9924
7	4.27 ± 0.05^{c}	4.87 ± 0.12^{b}	2.11± 0.00^{b}	28.60 ± 1.03^{a}	0.9924

J_0: Instantaneous compliance, J_m: Viscoelastic compliance, J_{max}: Maximum creep compliance, λ: Retardation time, μ_0: Steady state viscosity.

* Central point of experimental design (triplicate).

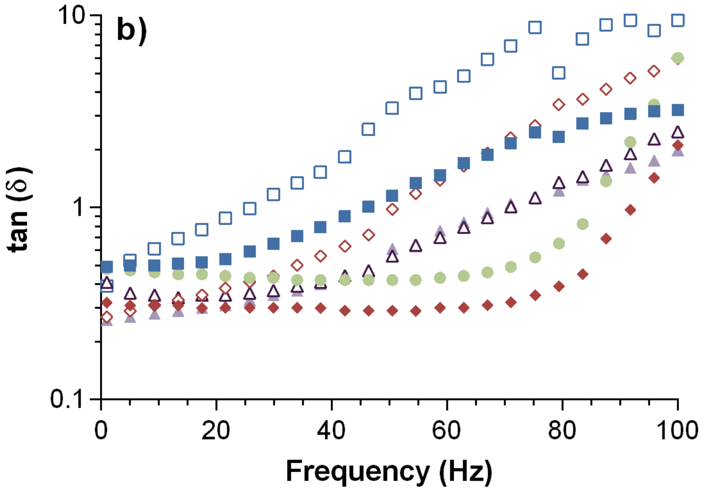
Values with different letters in the same column are significantly different ($p < 0.05$).

ACCEPTED MANUSCRIPT

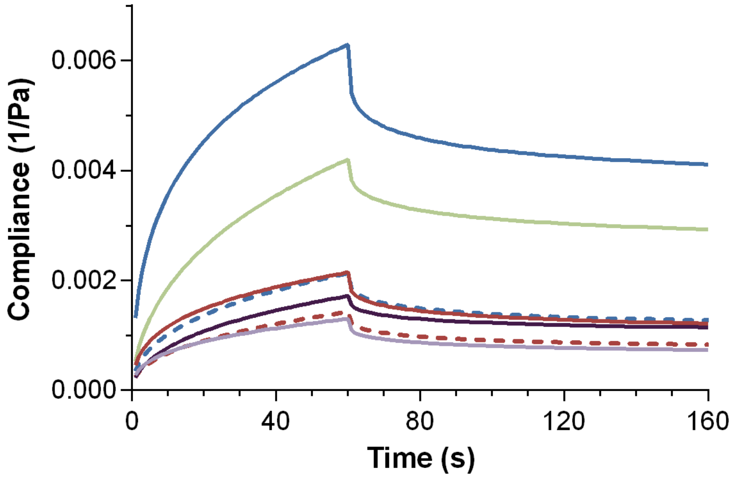


ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

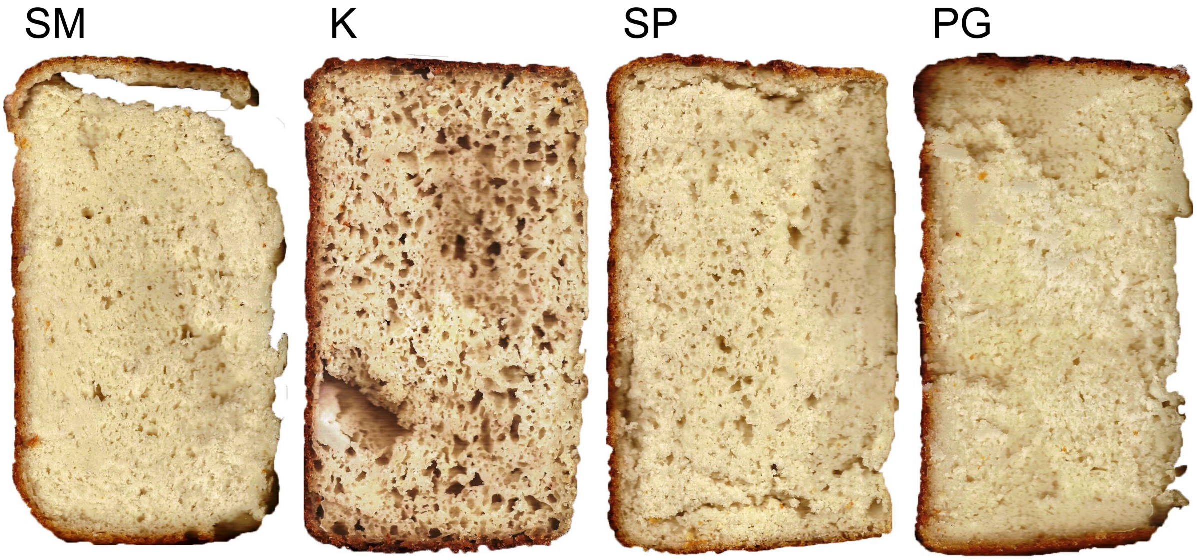


ACCEPTED MANUSCRIPT



ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT



ACCEPTED MANUSCRIPT

XG

GG

SA

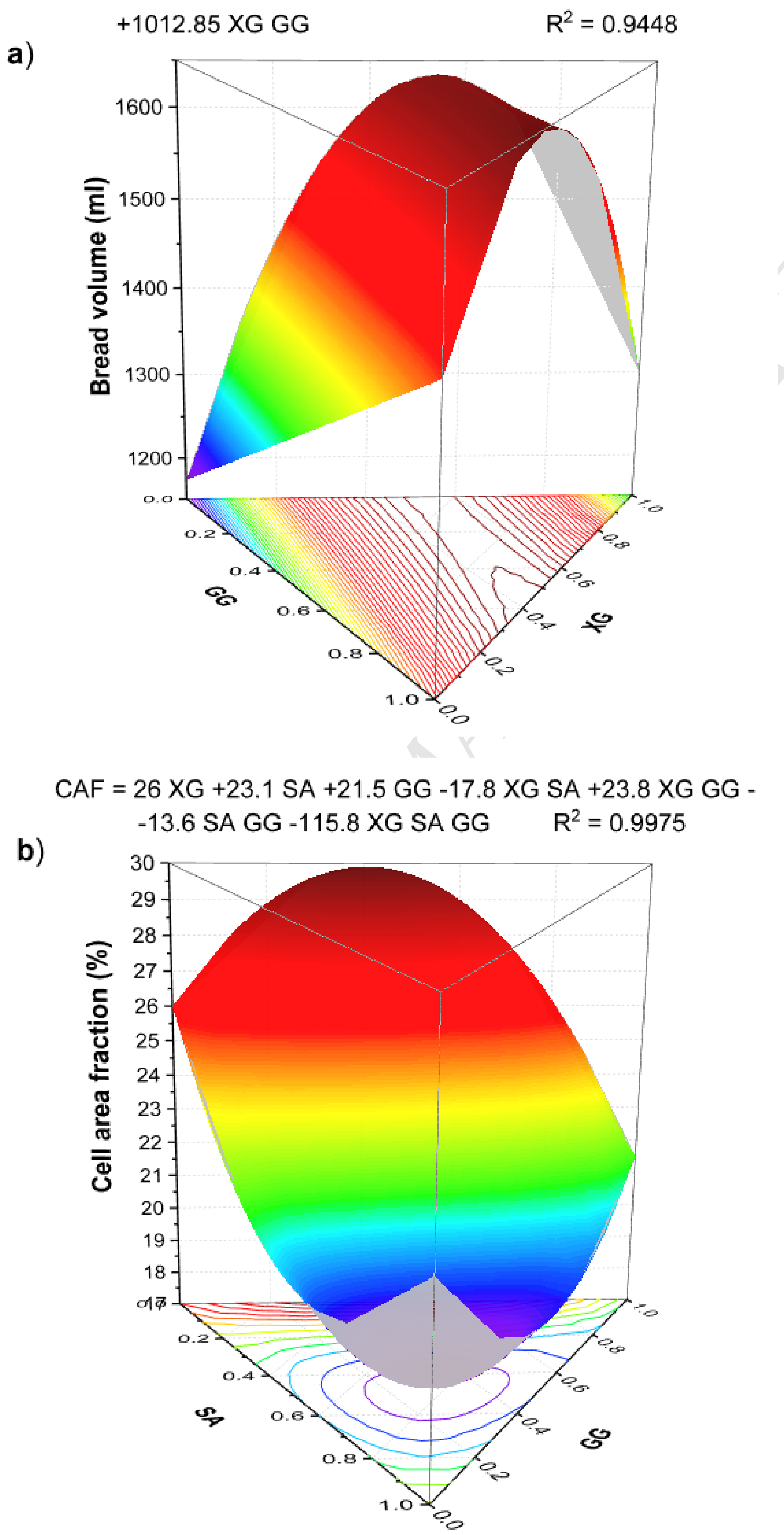
XG-GG

XG-GG-SA

SA-GG

XG-SA

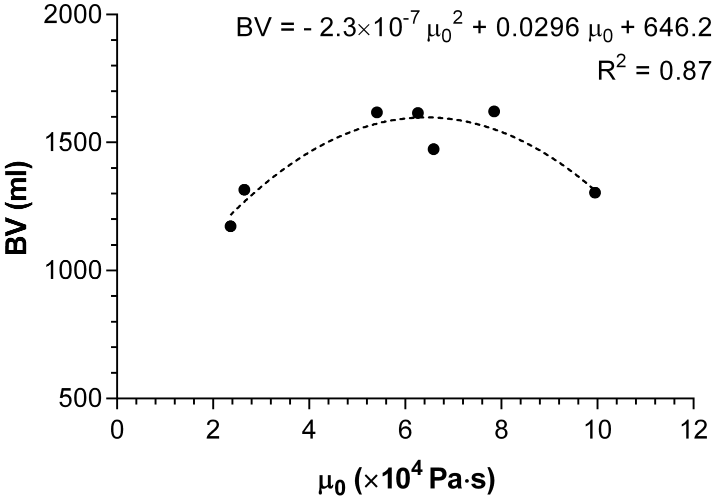
ACCEPTED MANUSCRIPT



$BV = 1299.49\ XG + 1173.17\ SA + 1474.17\ GG + 1586.85\ XG\ SA + 1012.85\ XG\ GG$ $R^2 = 0.9448$

$CAF = 26\ XG + 23.1\ SA + 21.5\ GG - 17.8\ XG\ SA + 23.8\ XG\ GG - 13.6\ SA\ GG - 115.8\ XG\ SA\ GG$ $R^2 = 0.9975$

ACCEPTED MANUSCRIPT



ACCEPTED MANUSCRIPT

ACCEPTED MANUSCRIPT

Highlights

- Several rice flours and gluten substitutes were evaluated to produce rice bread.
- Bread quality was estimated from bread volume and gas cell parameters.
- Mixture design was adopted to perform the optimization of bread formulation.
- The effect of formulation on dough rheology was also studied.
- Correlations among bread quality attributes and dough viscosity were obtained.

ACCEPTED MANUSCRIPT