

15 **Research Highlights**

- 16 • A gluten free bread from germinated brown rice was developed
- 17 • Germination time of the rice affected flour properties and bread quality
- 18 • Flours obtained after 24 hours of germination led to an improvement in bread
- 19 texture

20

21 **ABSTRACT**

22 The effect of germination time on physicochemical characteristics of brown rice flour and
23 its effect on gluten free bread qualities have been investigated. Germination was carried
24 out at 28°C and 100% RH for 12, 24 and 48 hours; brown rice and soaked brown rice was
25 also analyzed. Significant changes on hydration and pasting properties of brown rice flour
26 were found during germination. The starch degradation by enzyme activity could be
27 evidenced with the decrease in viscosity and water binding capacity (WBC). No significant
28 effect in specific volume, humidity and water activity of the gluten free bread was found as
29 germination time increase, but a significant softness of the crumb was obtained. However,
30 at 48 hours of germination, the intense action of α amylase could result in excessive
31 liquefaction and dextrinisation, causing inferior bread quality. Overall, germinated rice
32 flour showed appropriate functionality for being used as raw ingredient in gluten free
33 breadmaking.

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35 **Key words:** germinated brown rice, gluten free bread; quality.

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37

38 1. INTRODUCTION

39 Rice flour is one of the elected cereals for obtaining gluten free baked goods when those are
40 addressed to gluten intolerant patients. Many studies have been focused on making rice
41 flour based leavened baked gluten free products, and specifically bread (GFB) (Rosell and
42 Gomez 2014). Rice flour is the side product of the rice milling industry but flour properties
43 are definitive in the gluten free bread quality, as has been reported when assessing the
44 impact of rice variety (Han et al. 2012), and particle size of the flour and length of rice
45 grain (de la Hera et al. 2013). Having in mind gluten free bread quality, even treatments as
46 extrusion has been proposed for improving rice flour breadmaking functionality (Martinez
47 et al. 2014). In general, GFB are made from refined flours, which have lost very important
48 nutritional compounds like fibers, vitamins and minerals. Nevertheless, endogenous
49 constituents of the rice grain cannot be put back when using refined rice flour, resulting in a
50 detrimental effect on the nutritional quality of the food.

51

52 Germinated brown rice flour (GBRF) and germinated glutinous brown rice flour have been
53 used as functional food ingredients in breadmaking (Charoenthaikij et al. 2010a; 2010b;
54 2012; Watanabe et al. 2004), due to its high content in bioactive compounds such as γ -
55 aminobutyric acid and antioxidants such as phenolic compounds, γ -oryzanol and vitamin E
56 (Cáceres et al. 2014). The benefits of these bioactive compounds include regulation of
57 blood pressure and heart rate, alleviation of pain and anxiety, inhibition of cancer cell
58 proliferation, and protection for oxidative stress (Oh and Oh 2004). Despite their nutritional
59 benefits, germinated brown rice flour, pregerminated brown rice flour and germinated
60 glutinous brown rice flour have been only used for partial substitution (10-30%) of wheat
61 flour in breadmaking (Charoenthaikij et al. 2010a; 2010b; 2012; Watanabe et al. 2004).

62 This practice produces changes in the rheological properties of the batter, modifying dough
63 handling, besides an improvement of crumb texture, increase of gas production during
64 fermentation and retard bread staling (Charoenthaikij et al. 2010b; Watanabe et al. 2004).
65 The late benefit likely related to the alfa-amylase action forming low molecular weight
66 dextrin that could inhibit amylopectin retrogradation (Gray and Bemiller 2003). In addition,
67 germination could produce an excessive liquefaction and dextrinisation of starch granule,
68 producing ‘wet sticky crumb’ (Hallén et al. 2004), because of that it is necessary to define
69 the right germination time for optimizing flour breadmaking features. Nevertheless, no
70 attempts have been made in using germinated rice brown flour for obtaining gluten free
71 bread.

72

73 The aim of this study was to analyze the effect of germination time in physicochemical
74 characteristics of the flour and the effect of use GBRF as primary ingredient of GFB on
75 bread quality.

76

77 **2. MATERIAL AND METHODS**

78 Commercial certified brown rice cultivar INIAP 15 was provided by the National Institute
79 of Agricultural Research from Ecuador (INIAP). Seeds were harvest between May and
80 December 2011. The gluten-free bread formulations also contained compressed yeast
81 (LEVAPAN, Lessafre, Madrid, Spain) and hydroxypropylmethylcellulose Methocel K4M
82 obtained from Dow Chemical Company (Michigan,USA).

83

84 2.1.Germination and Flour preparation

85 Brown rice was sterilized with 0.1% sodium hypochlorite solution (1:5 w/v) for 30 min,
86 and then rinsed with distilled water. Afterwards, rice was soaked in distilled water (seed
87 water ratio, 1/5, w/v) for 24 h at 28 ± 1 °C. Soaking water was drained and seeds were placed
88 in plastic trays containing moist filter and were also covered with moist filter paper. The
89 filter papers were kept wet by capillarity. Germination was carried out at 28 ± 1 °C and
90 100% relative humidity under darkness for 12, 24 and 48 hours. After germination, seeds
91 were dried at 50 ± 1 °C for 24 hours. Once dried, seeds were ground until a diameter inferior
92 to 1mm with a cyclone mill (UDY Corporation, USA). Five treatments were analyzed,
93 brown rice flour as reference, soaked rice flour and germinated for 12, 24 and 48 hour rice
94 flour. Two sets of samples were prepared for each treatment.

95

96 2.2. Flour hydration properties

97 The water holding capacity (WHC) defined as the amount of water retained by the sample
98 without being subjected to any stress was determined mixing $1.000\text{g} \pm 0.001\text{g}$ of flour with
99 distilled water (10 ml) and kept at room temperature for 24 h. WHC was expressed as
100 grams of water retained per gram of solid. The swelling volume (SV) was determined
101 following the method reported by Gularte and Rosell (2011) with slight modification.
102 Samples ($1\text{g} \pm 5\text{mg}$) were placed in a graduated cylinder and mixed with distilled water (10
103 ml), then kept at room temperature for 24 h. The swelling volume was calculated by
104 dividing the total volume of the swollen sample by the original dry weight of the sample.
105 The water binding capacity (WBC) defined as the amount of water retained by the sample
106 under low-speed centrifugation was determined as described the standard method (AACC
107 2010). Samples ($1.000\text{g} \pm 0.001\text{g}$) were mixed with distilled water (10 ml) and centrifuged

108 at 2000xg for 10min. WBC was expressed as grams of water retained per gram of solid. All
109 the analyses were made in triplicate.

110

111 2.3. Flour Gel hydration properties

112 Water absorption index (WAI), water solubility index (WSI) and the swelling power (SP)
113 of different rice flour fractions were determined following the method of Anderson et al.
114 (1969) with slight modification. Briefly, flour (50.0mg ± 0.1mg) sample was dispersed in 1
115 ml of distilled water in an Eppendorf tube using a wire rod and cooked at 90 °C for 15 min
116 in a water bath. The cooked paste was cooled with ice to room temperature, and then
117 centrifuged at 3000x g at 4°C for 10 min. The weight of dry solids was recovered by
118 evaporating the supernatant overnight at 110 °C. Four replicates were made for each
119 sample. WSI, WAI and SP were calculated by the equations 1 to 3:

$$120 \quad WAI \text{ (g/g)} = \frac{\text{Weight of sediment}}{\text{Sample weight}} \quad \text{Eq. 1}$$

121

$$122 \quad WSI \text{ (g/100g)} = \frac{\text{Weight of dissolved solids in supernatant}}{\text{Sample weight}} \times 100 \quad \text{Eq. 2}$$

123

$$124 \quad SP \text{ (g/g)} = \frac{\text{Weight of sediment}}{(\text{Sample weight} - \text{Weight of dissolved solids in supernatant})} \quad \text{Eq. 3}$$

125

126 For the determination of oil absorption capacity (OAC), the method of Lin et al. (1974) was
127 followed. Briefly, flour sample (100.0mg ± 0.2mg) was mixed with 1 ml of vegetable oil.
128 The content was stirred for 1 min with a wire rod to disperse the sample in the oil. After a
129 period of 30 min in the vortex mixer, tubes were centrifuged at 3000 x g and at 4°C for 10
130 min. The supernatant was carefully removed with a pipette and tubes were inverted for 25

131 min to drain the oil prior to re-weighing. The oil absorption capacity was expressed as
132 grams of oil bound per gram of the sample on dry basis. Three replicates were made for
133 each sample. OAC was calculated by the equation 4:

134

$$135 \quad OAC \text{ (g/g)} = \frac{\text{Weight of sediment after draining oil}}{\text{Sample weight}} \text{ Eq. 4}$$

136

137 2.4.Determination of pasting properties of rice flours

138 Pasting properties of the rice flour were determined using a rapid viscoanalyser (RVA)
139 (Newport Scientific model 4-SA, Warriewood, Australia) by following ICC standard
140 method No 162 (ICC 1996). Sample (3 g based on 14% moisture) was added to 25 mL of
141 water. The suspension was heated at 50 °C for 1 min and then heated up to 95 °C at
142 12°C/min. After holding at 95 °C for 2.5 min, the suspension was cooled to 50 °C at
143 12°C/min. The rotational speed of the paddle was maintained at 160-rpm throughout the
144 run, except during the first 10 s, when a 960-rpm speed was used. Peak viscosity,
145 breakdown, final viscosity and setback (difference between final viscosity and peak
146 viscosity) were evaluated.

147

148 2.5.Breadmaking and evaluation of bread quality

149 The dough was prepared using the formula of Marco and Rosell (2008). Half of the rice
150 flour was mixed with boiling water (half of the water) in a Brabender Farinograph
151 (Duisburg, Germany) for five minutes. The dough was left to rest until the temperature
152 decreased to around 30 °C. Afterwards, the rest of the flour and water, besides the other
153 solid ingredients, were added and mixed in a Brabender Farinograph (Duisburg, Germany)

154 for 5 min. Then, dough was transferred (180 g) to pans and fermented for 40 min at 35°C
155 and 85% RH. Finally, the fermented dough was baked 35 min at 175°C. Loaves were
156 cooled down at room temperature for one hour and then packed in polyethylene pouches.
157 Further analysis was carried out after 24h of baking.

158 Bread quality properties included specific loaf volume, height/width ratio of the slices,
159 crumb color and its texture including hardness, springiness, resilience, chewiness and
160 cohesiveness. The loaf volume was determined by rapeseed displacement, while the
161 specific volume (mL g⁻¹) of the bread was calculated as the ratio of the volume (mL) to
162 the weight (g) of the bread.

163 The crumb color was determined by the computer vision system (Yam and Papadakis
164 2004). The computer vision system station included a light source, a camera (canon SX500
165 IS, 16 mega pixel) and software (Adobe Photoshop CS5) for image processing and
166 analysis. The texture profile analysis (TPA) of the breadcrumbs was performed by a
167 Texture Analyzer CT3 (Brookfield, Middleboro, USA). A bread slice of 1-cm-thickness
168 was compressed up to 50% of its original height at a crosshead speed of 1 mm/s with a
169 cylindrical acrylic probe (diameter 25.4 mm).

170

171 2.6. Statistical analysis

172 Standardized skewness and standardized kurtosis analyses were made to verify normal
173 distribution of the data. Multiple sample comparison was conducted to evaluate significant
174 differences among samples by analysis of variance (ANOVA) and multiple range tests.
175 Fisher's least significant differences (LSD) test was used to describe means with 95%
176 confidence ($P < 0.05$). Data was also evaluated using Pearson correlation coefficients to
177 establish relationship among variables. Only correlation coefficients (in absolute value)

178 equal or greater than 0.68 were considered meaningful. All statistical analyses were
179 performed using Statgraphics Centurion 16 (Statistical Graphics Corporation, UK).

180

181 **3. RESULTS AND DISCUSSIONS**

182 3.1. Flour and flour gel hydration properties:

183 The Table 1 shows the hydration properties of brown rice, soaked and germinated brown
184 rice flour and their gels. It can be seen that there was a decreasing trend on the hydration
185 properties of the flour (WBC, WHC and SV) as germination time increased, although that
186 decrease was only significant in the case of WBC. During germination, enzyme activities
187 like the α -amylase increases, which led to starch degradation and subsequent increase of
188 small dextrins and fermentable sugar (Islam and Becerra 2012). The starch degradation
189 might induce the release of the water entrapped within the starch granule, and that effect
190 was even more dramatic as the starch hydrolysis proceeds and thus at extended
191 germination, reducing the flour hydration properties. Additionally, the released sugars from
192 starch hydrolysis during germination could form crosslinks between starch chains in the
193 amorphous regions of a starch granule, which restricted starch swelling (Baek et al. 2004)
194 also they could interact with water hindering the water available for starch hydration
195 (Peroni-Okita et al. 2013). The water binding capacity (WBC) and water holding capacity
196 (WHC) are important properties for bakery process, and become even more essential for
197 making gluten free baked goods. Texture or consistency of dough depends on water
198 absorption leading to body thickening and viscosity (Aguilera et al. 2011). High water
199 absorption reduces stickiness and produces stiff dough (Han et al. 2012). At bread level,
200 Han et al. (2012) found that rice lines with low water absorption produce fresh bread with a
201 suitable volume and firmness. Presumably, that effect could explain texture improvement

202 observed when partial replacement of wheat flour with germinated rice and pregerminated
203 rice (Charoenthaikij et al. 2010b; Watanabe et al. 2004). It is interesting to notice that WHC
204 of the soaked sample was significantly lower than that of samples germinated for 12 hour
205 and 24 hours. Again, this result could be explained due to α amylase action that takes some
206 time to degrade intact starch granules, changing its structure. Hydration properties of the
207 flour gel (WAI and SP) were not significantly affected as germination time increases, with
208 the exception of 48H germination. This could be also explained by the change produced in
209 the starch structure and the presence of released sugars that will interact with the starch
210 forming more compact gels. In contrast, water soluble index (WSI) increased as the
211 germination time increases, which confirmed the action of enzymes during germination and
212 thus the release of water soluble compounds. The oil absorption capacity (OAC) remained
213 constant until 24 hours of germination and only increased after 48 hours germination.

214

215 3.2. Flour Pasting Properties

216 The pasting plots and the recorded pasting properties of brown rice, soaked and germinated
217 brown rice flour are shown in figure 1 and table 2, respectively. A progressive reduction of
218 the viscosity during heating and cooling was observed as the germination proceeded, which
219 agree with previous reports (Charaenthakij et al. 2012). Soaking induced a significant
220 decrease of the viscosity after reaching the maximum viscosity during heating, which
221 resulted in much lower viscosity after cooling. It seems that soaking process was enough to
222 activate amylases and their activity became evident after starch gelatinization and during
223 cooling where amylose recrystallization occurs. After 12 hours germination (12H) only
224 slight increase in the peak viscosity was detected, likely due hydrolysis products were
225 washed out after soaking. Despite intact granules are less susceptible to amylase action,

226 giving sufficient time starch can be degraded and sugars are released (Dura et al. 2014). At
227 48 hour of germination the viscosity plot was drastically reduced during heating and
228 cooling, owing to extensive degradation of starch granules. It might be expected that at this
229 degree of degradation flour would not be suitable for breadmaking. Therefore, it seems that
230 germination induced enzyme activation and that might respond to an exponential curve, as
231 revealed the great action on the starch after 48H germination. The reduction of starch
232 content with a simultaneous increase of reducing sugars content during germination have
233 been previously reported (Charaenthakij et al. 2012; Wu et al. 2013).

234

235 Peak viscosity, breakdown, setback and final viscosity decreased with germination due to
236 degradation of the starch by the enzyme activity (Charoenthaikij et al 2009; 2012, Mäkinen
237 et al. 2013; Wu et al. 2013). The action of α amylase changes the structure of the starch
238 molecule breaking down the polymers chains and reducing its ability to bind water and
239 increase the viscosity. The setback value reflects the degree of retrogradation of amylose
240 (Gani et al. 2013). Thus, germination reduces the ability of amylose to retrograde, which
241 might be beneficial in breadmaking to reduce the gluten free bread tendency to stale during
242 storage.

243 It is interesting to notice that breakdown, related to starch cooking stability (Rojas et al.
244 1999), increased until 12 hours of germination. Previous studies about germination reported
245 a breakdown decrease due to this process (Charoenthaikij et al 2012; Mäkinen et al. 2013;
246 Wu et al. 2013). However, those studies did not analyzed soaking and the first stage of
247 germination (after 12 hours of germination). A high breakdown demonstrates the ease of
248 starch granules to be broken upon heating after the maximum swelling at the peak viscosity
249 (Rojas et al. 1999). These results could demonstrate that during soaking and the first hours

250 of germination starch granule was more susceptible to breaking, likely due to starch
251 annealing or internal structure organization.

252

253 3.3.Evaluation of Bread Quality

254 Figure 2 displays cross section bread slices from brown, soaked and germinated rice flour.

255 As germination time increased the crumb structure showed more elongated gas cells and of
256 increasing size, which occurred up to 24 hours germination (24H). Mäkinen et al. (2013)

257 observed a reduction of batter viscosity with the use of malted cereal, which enhanced α

258 amylase activity, and those batters led to breads with more open crumb. Intermediate or

259 lower paste viscosities could favor expansion of batters during baking resulting in large

260 specific volume and more open crumbs (Renzetti and Arendt 2009). Indeed, the increase in

261 amylase activity and sugar content due to germination produced faster increase of the batter

262 volume during fermentation allowing the formation of large holes in the center of the

263 crumb. However, no significant correlation was found among specific volume and pasting

264 properties. Actually, at 48 hour of germination (48H GB) the crumb became deteriorated

265 due to an excess of amylase activity, which, as it was discussed before in the pasting

266 properties, induced complete degradation of starch. In fact, the presence of high level of α

267 amylase could result in excessive liquefaction and dextrinisation, causing an inferior quality

268 of bread described by the term 'wet sticky crumb' (Hallen et al. 2004). In addition, it can be

269 observed that as germination time increased the surface became flattened; really at 24 hours

270 of germination it was more concave. This result suggests that as the germination time

271 increased the fermentation time should be decreased because fermentable sugars released

272 from α amylase action speed up the leavening. Fermentation was carried out at fixed time

273 for comparing flours behavior, but even crumb structure revealed an over-fermentation in
274 breads obtained from germinated flour.

275

276 Quality characteristics of gluten free bread from brown, soaked and germinated rice flour
277 are shown in table 3. No significant differences were found in the humidity, water activity
278 and specific volume between samples, implying that germination does not produce
279 significant changes in these bread characteristic. Although breads showed a significant
280 higher specific volume than the bread obtained from non-germinated flour. A strong
281 correlation was found between humidity and pasting properties such as peak viscosity
282 ($r=0.92$ $P<0.001$), breakdown ($r=0.74$ $P<0.01$), final viscosity ($r=0.89$ $P<0.01$) and setback
283 ($r=0.86$ $P<0.01$) as well as humidity and WHC ($r=0.73$ $P<0.01$), although those could not
284 be related with bread quality properties. A negative correlation has been reported between
285 dough consistency at cooling and specific volume of rice based gluten free breads (Matos et
286 al. 2013) and a positive correlation between apparent viscosity and loaf volume (Sabanis et
287 al. 2009), but no correlation was observed when germinated rice flour was used as raw
288 material.

289

290 No significant effect was observed on the geometry (width/height) of the breads due to the
291 time of germination, although a tendency to increase with the germination time was
292 envisaged. A strong correlation was found between width/height and SV ($r=0.79$ $P<0.001$).
293 The specific volume values of the samples ranged from 1.5 to 2.3 ml/g, these results are in
294 agreement with the ones reported for rice GFB (de la Hera et al. 2013; Matos and Rosell
295 2012; Marco and Rosell 2008b).

296

297 Generally rice gluten free breads are rather pale due to the refined flour use in their
298 production, because of that crumb color becomes of importance when developing this type
299 of baked products. CIE $L^*a^*b^*$ scale was used to characterize crumb color. L^* value
300 showing the lightness of the crumb (table 3) underwent a significant reduction as the
301 germination time increased, which is desirable because GFB tends to have lighter color
302 than wheat bread. The L^* values ranged from 54.9 to 73.5, which are within the lower
303 values reported in commercial gluten free rice breads (Matos and Rosell 2012). All the
304 samples, except soaked flour, showed positive values for a^* , which are associated with
305 reddish color, also b^* positive values were found, indicating yellowish tone. Indeed, a^* and
306 b^* values increased as the germination time was extended. Those parameters showed
307 higher values than the ones reported in commercial gluten free rice bread (Matos and Rosell
308 2012). All the samples showed a positive hue angle that reflected yellow-orange hue.
309 Chroma values associated with the purity of color were higher than the ones obtained with
310 commercial gluten free breads, which revealed its higher purity of color related to major
311 intensity of the yellow component. In fact, Charoenthaikij et al (2010a) reported an increase
312 of yellowness of bread with the addition of germinated brown rice flour to wheat flour.
313 Hence, the increase of the chroma value could be due to the increase of reducing sugar
314 during germination.

315

316 Significant differences were observed in the crumb texture properties among grain
317 treatments (table 4). The hardness values were lower than 10 N, that are inferior than those
318 reported in commercial GFB (Matos and Rosell 2012), but still harder than wheat bread
319 with hydroxypropylmethylcellulose (1.96 ± 0.19 N) reported by Bárcenas and Rosell
320 (2005). Considering that GFB present high crumb hardness due to their complex

321 formulation, these values are sought after (Matos and Rosell, 2011). As the germination
322 time increased the hardness of the crumb decreased, the degradation of starch during
323 germination could cause a decrease of crumb hardness, probably due to the formation of
324 thinner cell walls that led to softer crumbs. Also, Charoenthaikij et al. (2010a) found that a
325 partial substitution with germinated brown rice flour reduces hardness of wheat bread
326 compared to brown rice flour.

327

328 High springiness values are preferred because it is related to the freshness and elasticity of
329 the bread. As the germination time increased, the springiness value decreased, indicating an
330 increase in fragility and tendency to crumble when is sliced (McCarthy et al. 2005). Indeed,
331 after 12 hours of germination springiness values were lower than the ones reported before
332 in gluten free rice bread (Marcos and Rosell 2008; Matos and Rosell 2012). These low
333 values can be a limiting factor for the use of germinated brown rice for GFB. The lowest
334 value was found at 48 hours of germination; actually the bread was too fragile that was
335 difficult to cut. The intense action of α amylase after 48 hour of germination could result in
336 excessive liquefaction and dextrinisation, causing inferior bread quality (Hallen et al.
337 2004). Not only springiness but also resilience characterizes the loss of elasticity, because it
338 indicates the ability of a material to return to its original shape after a stress (Onyango et al.
339 2011). Resilience and chewiness values decreased with the germination time. These values
340 agree with those reported previously in commercial GFB (Matos and Rosell 2012).

341 The reduction of hardness and chewiness could be also related to the results found by
342 Renzetti and Arendt (2009) when using protease treatment to improve the baking quality of
343 brown rice bread. The formation of low molecular proteins and carbohydrates by
344 germination yielded lower batter consistency and paste viscosity besides a decrease in

345 WBC, overall they might improve texture as previously reported (Charoenthaikij et al.
346 2010b; Watanabe et al. 2004).

347

348 Thus, it is important to bear in mind a reformulation when a germinated brown rice is used
349 as raw material, and it would be advisable to use brown rice up to 24 hours of germination
350 to develop GFB. Higher germination time could be used as a partial substitute for
351 increasing nutritional value of GFB.

352

353 **4. CONCLUSIONS**

354 Germinated rice flour showed appropriate functionality for being used as raw ingredient in
355 gluten free breadmaking. The germination time of the rice has a significant effect on flour
356 properties and the resulting bread quality. Specifically, flours obtained after 24 hours of
357 germination led to an improvement in bread texture, which might be ascribed to the
358 increase of amylase activities as well as starch degradation, which agrees with hydration
359 and pasting results. Also bread color improved as a result of non-enzymatic browning
360 reaction. However, excessive germination deteriorated the product as a result of extensive
361 amylolysis. Germinated rice flour of more than 24 hours of germination was not suitable
362 for breadmaking.

363

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372

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460

461 **FIGURE CAPTIONS**

462 **Fig 1** Pasting curves of brown, soaked and germinated rice flour.

463 **Fig 2** Gluten free bread slices from brown, soaked and germinated brown rice flour.

Table 1. Hydration properties of brown, soaked and germinated rice flour and their gel.

Treatment	WBC (g/g)	WHC (g/g)	SV (ml/g)	WAI (g/g)	WSI (g/100g)	SP (g/g)	OAC (g/g)
Brown Rice	1.52±0.03 ^a	1.68±0.14 ^a	3.10±0.00 ^a	11.64±0.21 ^a	0.03±0.00 ^c	12.02±0.23 ^a	1.59±0.01 ^b
Soaked	1.39±0.04 ^b	1.23±0.05 ^c	3.03±0.06 ^a	9.72±0.31 ^b	0.05±0.01 ^b	10.27±0.35 ^b	1.63±0.02 ^b
12H GF	1.35±0.02 ^b	1.43±0.07 ^b	3.00±0.00 ^a	9.87±0.22 ^b	0.06±0.01 ^b	10.63±0.52 ^b	1.63±0.07 ^b
24H GF	1.26±0.04 ^c	1.55±0.18 ^{ab}	2.43±0.12 ^b	9.95±0.25 ^b	0.05±0.01 ^{bc}	10.46±0.28 ^b	1.60±0.01 ^b
48H GF	1.02±0.04 ^d	0.89±0.01 ^d	2.49±0.00 ^b	5.65±0.31 ^c	0.15±0.03 ^a	6.46±0.55 ^c	1.71±0.02 ^a

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 ($P<0.05$).

Table 2. Pasting properties of brown, soaked and germinated rice flour.

Treatment	Peak viscosity (cP)	Breakdown (cP)	Final viscosity (cP)	Setback (cP)
Brown Rice	1926±4 ^a	468±24 ^c	4222±78 ^a	2295±43 ^a
Soaked	1602±4 ^c	651±14 ^b	3500±9 ^b	1897±13 ^b
12H GF	1833±38 ^b	697±7 ^a	3522±30 ^b	1689±9 ^c
24H GF	1409±6 ^d	683±9 ^{ab}	2560±3 ^c	1151±3 ^d
48H GF	229±1 ^e	200±6 ^d	172±11 ^d	58±12 ^e

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

Table 3. Quality characteristics of gluten free brown rice bread from brown, soaked and germinated rice flour.

Treatment	Specific Volume (ml/g)	Humidity (%)	Aw	Width/Height	<i>L</i> *	<i>a</i> *	<i>b</i> *	Chroma	Hue angle (°)
Brown Rice	1.52±0.06 ^b	50.46±2.98	0.97±0.00	1.49±0.19 ^a	73.54±1.33 ^a	0.34±2.74 ^{bc}	37.85±2.79 ^{ab}	37.93±2.87 ^{ab}	89.53±3.91 ^{ab}
Soaked	2.28±0.04 ^a	50.08±1.39	0.98±0.01	1.36±0.03 ^b	66.35±7.78 ^b	-0.35±1.93 ^c	35.12±3.44 ^b	35.17±3.49 ^b	90.35±2.91 ^a
12H GF	1.99±0.45 ^a	50.46±1.72	0.98±0.00	1.42±0.09 ^{ab}	67.82±5.49 ^b	0.71±0.85 ^{bc}	35.82±3.03 ^b	35.84±3.04 ^b	88.90±1.28 ^{ab}
24H GF	2.14±0.33 ^a	49.98±0.75	0.98±0.00	1.49±0.10 ^a	65.57±4.96 ^b	1.42±1.17 ^{ab}	38.53±3.88 ^{ab}	38.57±3.86 ^{ab}	87.82±1.81 ^{bc}
48H GF	2.07±0.08 ^a	42.30±3.71	0.97±0.01	1.51±0.10 ^a	54.89±2.21 ^c	2.44±2.70 ^a	40.67±3.81 ^a	40.83±3.71 ^a	86.27±3.87 ^c

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

Table 4. Analysis of crumb texture of gluten free brown rice bread from brown, soaked and germinated rice flour.

Treatment	Hardness (N)	Resilience	Springiness	Chewiness (N)
Brown Rice	6.64±2.56 ^b	0.29±0.03 ^a	0.94±0.35 ^a	14.73±5.78 ^a
Soaked	9.16±1.48 ^a	0.21±0.05 ^b	0.82±0.30 ^{ab}	13.94±5.53 ^a
12H GF	5.37±2.39 ^{bc}	0.15±0.02 ^c	0.67±0.05 ^{bc}	5.25±2.91 ^b
24H GF	4.42±0.55 ^c	0.17±0.03 ^c	0.72±0.09 ^{bc}	5.68±0.82 ^b
48H GF	2.13±0.65 ^d	0.15±0.03 ^c	0.56±0.10 ^c	2.77±1.88 ^b

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

Fig 1

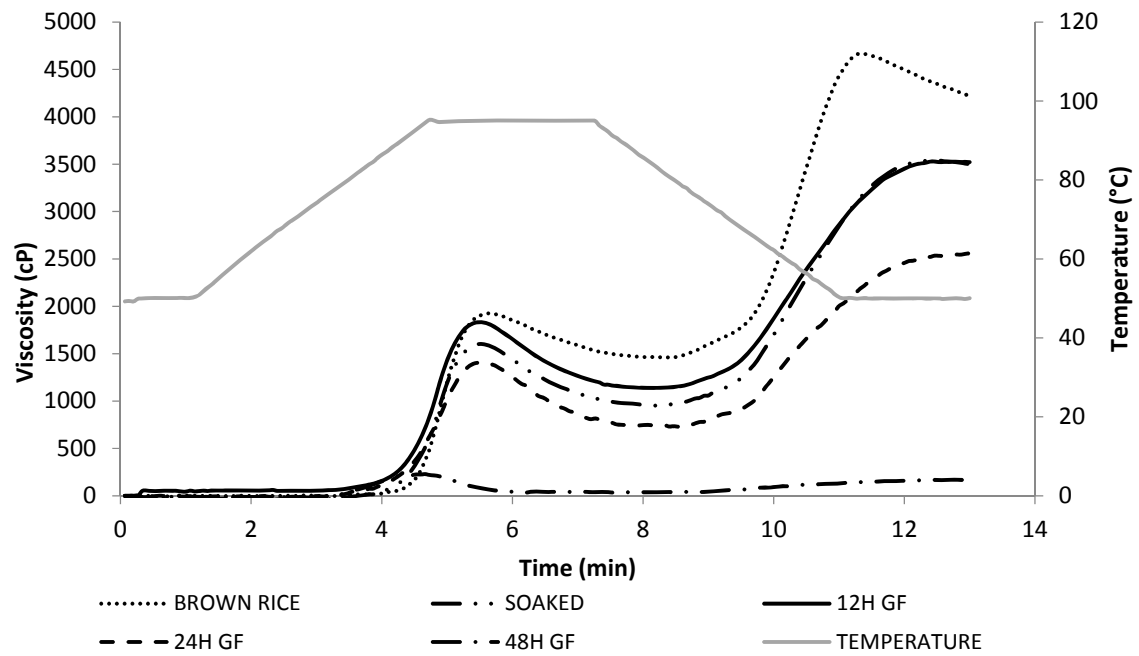


Fig 2

