Quality improvement of rice-based gluten-free bread using different dietary fibre fractions of rice bran

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A B S T R A C T
Gluten-free (GF) breads are often characterised by low nutritional quality as they are mainly starch based and contain low amounts of vitamins, minerals and in particular dietary fibre. The objective of this study was to improve the physical, nutritional and sensory quality and shelf life of rice-based GF bread by adding different fractions of rice bran, containing different amounts of protein, fat, dietary fibre (DF) and different ratios of insoluble (IDF) to soluble (SDF) DF.

As a first step, recipe parameters (content of HPMC, egg albumen and emulsifier) of GF bread with 10% rice bran addition were optimised. An amount of 3% HPMC, 1.5% emulsifier and 2% egg albumen provided acceptable structural and textural quality of GF bread. The main trials demonstrated that addition of rice bran, in particular when containing a high amount of SDF, produced better bread colour, higher specific volume, softer crumb firmness and improved porosity profile. All rice bran containing GF breads had higher protein and DF content and the ratio of IDF to SDF was improved substantially depending on the dietary fibre fraction of rice bran. Sensory acceptance was increased and shelf life extended, again when selecting a rice bran source with high SDF content.

1. Introduction

There is an increasing interest in gluten-free (GF) products as the prevalence of coeliac disease is increasing. Its mean prevalence is estimated to be 1–2% of the world population (Reilly and Green, 2012). Therefore, a major challenge for the food industry is to develop GF products with high nutritional value for wellbeing. However, still the majority of the commercial GF bread products are of lower quality when compared to wheat bread products. The major defects in basic GF bread are that they often present poor quality with a crumbling texture, dry and friable crumb, lack of flavour and mouth feel, poor colour, and other post baking defects (Gallagher et al., 2004). From a nutritional viewpoint, most gluten-free breads are low in protein and dietary fibre. In recent studies, various technological parameters and formulations have been extensively investigated to improve not only quality but also the nutritional value of GF bread by either using different raw materials (Schoenlechner et al., 2010; Sciarini et al., 2010; Torbica et al., 2010) or adding various additives (Sciarini et al., 2011) like hydrocolloids (Sabonis and Tzia, 2011), emulsifiers (Nunes et al., 2009) or proteins (Crockett et al., 2011; Marco and Rosell, 2008; van Riemsdijk et al., 2011). Although some studies on the use of dietary fibre in GF bread have been performed in recent years (Hager et al., 2011; Sabanis et al., 2009), research data on this topic is still limited and not sufficient to explain the effects of fibre addition on the functional and sensory quality of GF bread. Besides its well documented health benefits, dietary fibre addition contributes to the modification and improvement of texture, sensory characteristics and shelf-life of foods (due to its water binding capacity, gel forming ability, fat mimetic, textural and thickening effects), but most of this information has been learned from gluten-based food systems. In order to better understand the effects of using or adding whole-grain, various bran fibres, or other sources of dietary fibre to GF dough systems, further detailed research is necessary.

Rice flour is well accepted and one of the most used cereal grain flours for the production of GF products due to its bland taste, white colour, high digestibility, and hypoallergenic properties (Marco and Rosell, 2008). However, GF breads based on rice flour require polymeric substances that mimic the viscoelastic properties of gluten to provide structure and retain gas (Torbica et al., 2010). Hydroxypropyl methylcellulose (HPMC) is such a compound that could improve volume and texture of rice-based GF breads in terms...
of gas retention and water absorbing characteristics (Marco and Rosell, 2008; Sabanis and Tzia, 2011). Regarding nutritional quality, rice-based GF formulations have, in particular, low contents of vitamins, minerals, proteins and dietary fibre (Sciarini et al., 2010; Thompson et al., 2005). Consequently the enrichment of GF rice bread with dietary fibre seems to be necessary. Rice bran is a product obtained from the outer kernel layers and is used as raw material for the production of rice bran oil. However, a large amount of defatted rice bran (DFRB) is accumulated as a by-product, which is mainly used as animal feed. DFRB is a good source of protein, which is rich in lysine, and mineral content (Jiamyangyuen et al., 2005). Its total dietary fibre content ranges from 20 to 51% (Saunders, 1990). Although applications of rice bran in some foods have been reported (Hu et al., 2009; Sharif et al., 2009), addition of rice bran to GF bread has not yet been investigated.

There are two approaches to increase the nutritional value of GF, one is to use raw materials as wholegrain and the second is to add isolated dietary fibre sources to refined flour. The effects on the textural, nutritional and sensory quality of the final product will be different, but both approaches have the potential to enhance the nutritional quality of the final products. The advantage of adding isolated dietary fibre sources (bran fractions) which contain the majority of essential nutrients allows 1) selection of an appropriate milling fraction and 2) control of the amount of its addition and the study and optimisation of its effect on the functional properties of the resulting product. Based on this information, the objectives of this research were (1) to investigate the principal effect of adding rice bran to GF bread (based on refined rice flour and a dough system of protein/emulsifier/hydrocolloid) and to adapt its recipe parameters - amount of egg albumen, emulsifier and hydroxypropyl methylcellulose (HPMC) and (2) to study the effect of four different rice bran fractions of different chemical composition on the physical, sensory and nutritional quality as well as shelf life of GF bread based on rice flour.

2. Materials and methods

2.1. Materials

Four types of rice bran sources or fractions were chosen, which showed pronounced chemical differences in their chemical composition, in particular content of protein and dietary fibre, as well dietary fibre composition. The chemical compositions including protein, fat, total dietary fibre, insoluble dietary fibre and soluble dietary fibre are reported in Table 1. Defatted rice bran (DFRB) was obtained from Thai Edible Oil Co. Ltd. (Bangkok, Thailand) and is a by product from the rice bran oil production process. As a pre-treatment, it was steamed for 45 min and dried for 12 h at 50 °C in order to inactivate enzyme and microorganism activities. Until usage, it was stored at 4 °C. Three types of commercial rice bran sources (Risolubles, Ribifer and Ribran 100) were donated from NutraCear™, Scottsdale, USA. According to the available information from the company, Ribran consists of whole rice bran and rice germ. Risolubles consists of the water-based soluble fibre fraction, while Ribifer is the insoluble fibre fraction from rice bran. Rice flour was obtained from Strobl Caj. Naturmuhle GesmbH (Linz-Elbersberg, Austria), GF wheat starch from Kroener Staerke (Ibbenbueren, Germany; this wheat starch is tested for gliadin residues and certified for being gluten-free, while other commercial wheat starches often exceed the allowed gliadin limits), egg albumen powder from Enthoven-Bouwhuis Eiproducten B.V. (Raalte, Netherlands), vegetable fat powder (REVEL®-BEF) from Loders Croklaan B.V., Wormerveer, Netherlands. Hydroxypropyl methylcellulose (HPMC, Metolose® Shin-Entsu Chemical Co., Ltd., Tokyo, Japan) was donated by HARKE Pharma GmbH, Muelheim an der Ruhr, Germany and compressed baker’s yeast (Hagold Hefe GmbH, Vienna, Austria) was bought from the market. The emulsifier was a mixture of 3 parts diacetyl tartaric acid ester of monoglyceride (DATEM, Panodan M2020, Danisco®, Copenhagen, Denmark) and 5 parts distilled monoglyceride (DMG, Dimodan PH 100, NS/B, Danisco®, Copenhagen, Denmark).

Table 1

<table>
<thead>
<tr>
<th>Chemical composition</th>
<th>DFRB¹</th>
<th>Risolubles²</th>
<th>Ribifer²</th>
<th>Ribran²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein (% dm)</td>
<td>16.19</td>
<td>7.5</td>
<td>20.0</td>
<td>14.5</td>
</tr>
<tr>
<td>Fat (% dm)</td>
<td>2.5</td>
<td>26.5</td>
<td>13.0</td>
<td>20.5</td>
</tr>
<tr>
<td>Total dietary fibre (% dm)</td>
<td>20.3</td>
<td>3.0</td>
<td>42.0</td>
<td>29.0</td>
</tr>
<tr>
<td>Insoluble dietary fibre (% dm)</td>
<td>19.2</td>
<td>0.0</td>
<td>41.0</td>
<td>27.0</td>
</tr>
<tr>
<td>Soluble dietary fibre (% dm)</td>
<td>1.1</td>
<td>3.0</td>
<td>1.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

¹ Data determined by authors.
² Data provided by company.

2.2. Experimental design

In the first part of the study the effect of rice bran addition to GF rice-based flour was investigated and its recipe optimised by applying a 2² factorial screening design, where three factors (0—4% egg albumen, 0.5—1.5% emulsifiers and 1—3% HPMC) were varied. The basic GF bread recipe was chosen according to the state of the art for GF bread baking (system hydrocolloid/emulsifier/protein addition) and was: 100 g flour (mixture of GF wheat starch and rice flour at a ratio of 1:1), 10 g DFRB, 100 g water, 3 g yeast, 2 g salt, 2 g fat, 0—4 g egg albumen, 0.5—1.5 g emulsifier and 1—3 g HPMC. Type of emulsifier and hydrocolloid were selected according to pre-trials (results not shown here). The experiment with three replications of the centre point gave 11 formulas in total. Quality of bread was assessed as crumb colour, specific volume, textural properties (crumb firmness and relative elasticity) and porosity (number of pores, average pore diameter, pore size uniformity).

In the second part of the study, the influence of four different types of rice bran (DFRB, Risolubles, Ribifer and Ribran 100) at varying egg albumen content (0, 2 and 4%) on the quality of GF bread was investigated. The formula of GF bread was: 100 g flour (mixture of GF wheat starch and rice flour at a ratio of 1:1), 10 g rice bran, 100 g water, 3 g yeast, 2 g salt, 2 g fat, 0—4 g egg albumen, 1,5 g emulsifier and 3 g HPMC. A GF formula without rice bran addition containing 2% egg albumen and 100% water was used as control. From the best formula of each type of rice bran (0—4 g egg albumen) protein content, dietary fibre content, sensory properties and shelf life were determined. Selecting criteria were higher specific volume and lower crumb firmness.

2.3. Gluten-free bread production

Baking tests were carried out according to ICC Standard Method 131. All dry ingredients (wheat starch, rice flour, rice bran, egg albumen, vegetable fat powder, salt and emulsifier) were mixed in a mixer (Model KPM50, Kitchen Aid, St. Joseph, MI, USA) for 1 min. Compressed yeast was dispersed in the amount of water to be added and poured on to the dry mixture. The mixing process was continued for 6 min at step 2. Subsequently, the obtained GF batter was fermented for 30 min at 30 °C and 85% RH in a fermenter (Model G66W, MANZ Backtechnik GmbH, Creglingen, Germany). After that, the batter was then divided into two portions (450 g each), put into a tin (L × W × H: 15 × 11 × 7—13 × 9 × 7) and proofed for 50 min at 30 °C and 85% RH. The breads were then baked in a baking oven (Model 60/1W, MANZ Backtechnik GmbH, Creglingen, Germany) for 1 h at 180 °C. After baking, the breads...
were kept for 24 h at room temperature before determination of the quality characteristics.

2.4. Crust colour measurement

Colour measurement of crust was performed using a chromameter (Dr Lange, Microcolour Data Station, Dr Lange GmbH, Duesseldorf, Germany). \( L^\ast (0 = \text{black}, 100 = \text{white}), a^\ast (+\text{value} = \text{red}, -\text{value} = \text{green}), \text{and } b^\ast (+\text{value} = \text{yellow}, -\text{value} = \text{blue}) \) values were recorded. Three measurements from three different points of the crust of each loaf were taken, giving 6 values for each formula.

2.5. Specific volume and crumb textural properties measurement

Each loaf of bread was weighed and then measured for volume using a rapeseed displacement volumeter (Chopin Bread Volumeter, Tripetto & Renaud, Villeneuve La Garenne, France). Specific volume (cm\(^3\)/g) as the ratio of the volume (cm\(^3\)) and the mass of the bread (g) was calculated following the AACC Approved Method 55-50 (AACC, 2000). The measurements were made in triplicate, giving 6 values of each formula.

Crumb firmness and crumb relative elasticity were determined with a Texture Analyser (Model TA-XT2i, Stable Micro Systems™ Co, Godalming, GB) using a 5-kg load cell with an SMS 100 mm diameter compression probe (P100). From the central part of each loaf, cubes with the dimensions 4 \(\times\) 4 \(\times\) 3 cm (\(L \times W \times H\)) were cut using a sharp knife to prevent structural damage. For the determination of the textural and viscoelastic properties, a uniaxial compression test (30% compression) of the cube with subsequent relaxation phase was applied. The maximum force \(F_{\text{max}}\) needed to deform each cube was recorded and is referred to as crumb firmness. The relative elasticity (REL) in percent was calculated by dividing the residual force \(F_{\text{rem}}\) at the end of the holding time (120 s) by the maximum force \(F_{\text{max}}\) and multiplied by 100. All measurements were performed four times using two bread samples, giving 8 values in total for each formula.

2.6. Bread crumb porosity measurement

A 1 cm thick cross section of the bread was taken from the centre of each loaf for porosity measurement. An image analyser system (Olympus Zoom Stereo Microscope, model SZ4045TR with an SI-ILA Illuminator Base, Olympus Optical Co., Ltd, Hamburg, Germany, equipped with a Sony Colour Video Camera, model DXC-151, Tokyo, Japan, and a Sony Camera Adapter, model CMA-D2, Sony, Tokyo, Japan) was used to take a digital image (20 \(\times\) 20 mm) of the centre of the bread crumb. The DIGITRACE software package (Version 2.28, Imatec elektronische Bildanalyse-system GmbH, Miesbach, Germany) was used to analyse porosity values. Values determined were number of pores, average pore size (area), and standard deviation (SD) of average pore size (uniformity). The standard deviation of the average pore size was considered as a value indicating pore uniformity. The lower SD of pore area, the more alike was average pore size, indicating the higher was their uniformity. Four slices of each bread recipe were determined.

2.7. Analysis of crude protein and dietary fibre

Crude protein content of breads was determined according to the standard method of AOAC No. 42.05 (2000). Dietary fibre contents including total, insoluble and soluble dietary fibre were determined following the standard method of AACC No. 32-07 (2000) (Megazyme test kit, Megazyme International Ireland Ltd., Wicklow, Ireland). The gravimetric yield of soluble dietary fibre (SDF) and insoluble dietary fibre (IDF) were obtained after corrections for the content of ash, residual protein and the reagent blank. Total dietary fibre (TDF) was determined by summing SDF and IDF.

2.8. Sensory evaluation

The loaves were evaluated for acceptability of appearance, colour, odour, taste, texture and overall impression by an unstructured scale (10 cm) and anchored on both ends: bad (0) – good (10). The 37 panellists were students and staff members of the University of Natural Resources and Life Sciences, Vienna, Austria. The loaves were sliced into 1 cm thick slices, cut into half pieces of bread slice and immediately placed in plastic boxes to reduce product drying.

2.9. Shelf life of bread

The bread loaves were packed in paper bags and kept at 20 °C, 50% RH in a climate chamber. Samples were taken at day 1, 3, 5, 7 and 9 for determination of crumb firmness measurement. The duration of the shelf life test was terminated when all breads showed a crumb firmness value that exceeded the initial hardest value of the GF breads (DFRB). This happened only after 9 days of storage for Risolubles added bread, after 7 days it was still softer than the initial DFRB added GF bread. Bread staling was assessed using Avrami parameters. Values for the Avrami model factors were estimated by fitting experimental points into the non-linear regression equation 
\[
(T_a - T)/\left(T_a - T_0\right) = \exp\left(-kt^n\right)
\]
where \(T_0\) is the crumb hardness at zero time, \(T_a\) is the crumb hardness at \(\approx (=\text{final})\) time, \(T_i\) is the crumb hardness at \(t \text{ time}, k\) is a constant rate of the process (usually used 1/k time constant to compare bread hardening rate), and \(n\) is the Avrami exponent, which indicates the type of crystals growth.

2.10. Statistical analysis

Statistical analyses were performed using STATGRAPHICS Centurion XVI, version 16.1.05 (Statpoint Technologies, Inc., Warrenton, USA). To determine statistical significant differences between the samples, a multifactor ANOVA (analysis of variance differences tests \(= f\)-test for multiple samples, \(a = 0.05\) and Fishers least significance tests were applied. In the case of \(p\)-values less than 0.05, there is statistical significance in the effect of the factor on the functional properties analysed at the 95.0% confidence level; significant differences were indicated by different letters in the column.

3. Results and discussion

3.1. Addition of rice bran to rice-based GF bread and effect of egg albumen, emulsifiers and HPMC on GF bread quality

Table 2 shows the experimental responses related to the bread properties as well as the analyses of variance data. During pre-trials (results not shown here), the amount of DFRB addition to the basic GF bread was set at 10% addition. This recipe seemed most promising for further adaptation of bread quality. Results showed that egg albumen, emulsifier or HPMC had significant effects \((p < 0.05)\) on specific volume, crumb firmness, REL, \(L^\ast\) and \(a^\ast\)-values, but not on \(b^\ast\)-values of crust colour and porosity. Colour GF breads were dark brown with 61–77 for \(L^\ast\),...
1.6–8.3 for $a^*$ and 14.9–28.5 for $b^*$-values. Colour is an important characteristic for baked products and it is relevant to texture, aroma and consumer preference (Esteller and Lannes, 2008). In this study it was significantly influenced by the addition of emulsifier and HPMC. They both decreased darkness and HPMC additionally decreased redness. Albumen exerted no effect and no significant interactions between the investigated factors were observed. Decreased darkness after addition of emulsifier was also observed by Chin et al. (2007). They compared the effect of several emulsifiers (including DATEM and DMC) on bread quality and they found that emulsifier added breads had higher volume, higher oven spring, lower weight and density, whiter colour, finer crumb texture and longer shelf life compared to control breads.

Specific volume was significantly influenced by emulsifier and its interaction with HPMC. Higher addition of emulsifier and HPMC had a positive effect on bread volume. Crumb firmness was not significantly influenced by addition of emulsifier and HPMC, it was only tendentially decreased, resulting in a softer texture. REL was significantly decreased by emulsifier and HPMC. HPMC and emulsifier are well investigated and thus often applied as bread improvers. The mechanisms of HPMC and emulsifier as dough improvers are that HPMC forms a thermo-reversible gel on heating (Guarda et al., 2004) and forms interfacial films at the boundaries of the gas cells that confer some stability to the cells against the gas expansion and processing condition changes. Also, positive effects on GF bread formulations have been reported before (Mezaize et al., 2009 and others). Emulsifiers may bind to the protein hydrophobic surface promoting aggregation of proteins in the dough. A strong protein network results in better texture and increased volume of bread (Kamel and Ponte, 1993). The anti-firming properties of emulsifier are related to their ability to affect the amylose structure after baking and retard retrogradation (Goesaert et al., 2005).

In contrast to emulsifiers and HPMC, egg albumen had no significant influence on specific volume, but it significantly increased crumb firmness and REL of breads. This is consistent with the result of Schoenlechner et al. (2010) who reported that addition of egg albumen to gluten-free bread for up to 4% increased crumb firmness. Also Crockett et al. (2011) found that the addition of egg white solid lower than 10% did not improve loaf specific volume of GF breads, although van Riemsdijk et al. (2011) indicated that addition of protein content into GF would help gas cell stabilization and improve the bread properties.

The results suggested that the optimal formula of GF bread supplemented with 10% DFRB should have higher amounts of emulsifier and HPMC. However, the amount of egg albumen was not quite clear and was thus considered again in the main trials.

3.2. Influence of different types or fractions of rice bran and egg albumen on the quality of GF breads

Table 3 presents the results for colour, volume, texture and porosity measurements. Addition of all types of rice bran and bran fractions caused a significant increase in darkness ($L^*$) of bread crust colour ($p < 0.05$). The darkening effect was desirable as GF breads, in particular when based on rice flour, tend to have a lighter colour than wheat breads (Gallagher et al., 2003). No significant differences between the types of bran were observed on darkness, but on redness, addition of DFRB and Ribfer had a greater effect than Ribran and Risolubles. Yellowness was increased after addition of Risolubles and Ribran and decreased after addition of DFRB and Ribfer. Redness of crust was not affected by DFRB, decreased by Ribfer and increased by Risolubles and Ribran addition. Effects on crust colour were also observed after egg albumen addition; it increased darkness, redness and yellowness of the bread crust. Also Gallagher et al. (2003) found that GF breads became darker after addition of dairy powders, which they attributed to the formation of Maillard products.

Generally, in many studies, reduction of volume was found in wheat bread after supplementation with dietary fibre (Jiamyanguen et al., 2005; Ragae et al., 2011; Sangnak and Noomhorm, 2004) due to dilution of gluten in the flour blends. However, the results of this study demonstrated that the addition of most types of rice bran to GF bread increased specific volume. Only Ribfer showed no significant effect. Risolubles and Ribran demonstrated the highest volume increase, which probably can be attributed to their higher amount of soluble dietary fibre (3% in Risolubles and 2% in Ribran vs. 1% in Ribfer and 1.1% in DFRB). Crumb firmness was decreased after addition of all types of rice
bran. Risolubles showed the greatest effect, followed by Ribran, DFRB and Rifiber.

Egg albumen addition again increased crumb firmness as was observed in the first part of the study and its effect on volume and crumb firmness seemed to be dependent on the protein content of the bran source. In the case of Rifiber and DFRB, specific volume was gradually decreased and crumb firmness increased with increased egg albumen addition. Their higher protein content (20% and 16.2% DFRB) seemed to be sufficient for this GF bread recipe, further protein addition was obviously adverse affecting volume and crumb firmness as was gradual in Rifiber and DFRB as compared to the control bread. Highest protein content was found in bread supplemented with Rifiber (14.5% protein) and Risolubles (7.5% protein), additional 2% addition of egg albumen was sufficient, and this amount was not adversely affecting crumb firmness (while 4% again increased crumb firmness), REL was significantly decreased by about 4.6–12.7%, depending on the type of rice bran used. Albumen addition had only little effect on REL.

Results for crumb porosity measurement revealed that the control bread showed a non-continuous surface and big holes in the crumb structure as well as rather dense structure (Fig. 1). In addition, blisters were observed on the crust surface. Cell size and structure greatly influenced mouthfeel of a bread product; uniformly sized cells yield a soft and elastic bread texture, properties that are usually welcomed by consumers (Angioloni and Collar, 2009). Desirable are thus a high number of medium sized average pores of high uniformity. Supplemeting this GF bread with DFRB, Risolubles and Ribran improved crumb porosity to a great extend, it significantly increased pore diameter, resulting in a decreased number of pores and decreased uniformity (higher value of uniformity indicates higher variation of pore diameter size, thus decreased pore uniformity). Highest average pore diameter was found in the Risolubles and Ribran containing breads. No significant effects were observed after addition of Rifiber. Addition of higher amounts of egg albumen decreased average pore area but improved pore area uniformity. Four percent of albumen addition was needed to produce these effects. Number of pores was not significantly influenced by egg albumen. The reduction of the average pore size by albumen is probably due to a structure disruption by the increased egg albumen content, encompassing impairment in gas retention (Schoenlechner et al., 2010).  

### Table 3

Effect of different rice bran types and egg albumen content on bread quality properties.*

<table>
<thead>
<tr>
<th>Sample</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
<th>Specific volume (cm³/g)</th>
<th>Firmness (N)</th>
<th>REL (%)</th>
<th>Number of pores</th>
<th>Pore diameter (mm)</th>
<th>Pore size uniformity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>82.35±0.59a</td>
<td>2.95±0.42a</td>
<td>18.30±1.38a</td>
<td>3.05±0.00b</td>
<td>12.04±1.00b</td>
<td>52.01±0.97a</td>
<td>45.25±1.89a</td>
<td>3.39±1.38c</td>
<td>4.68±1.87c</td>
</tr>
<tr>
<td>DFRB 0</td>
<td>80.43±0.78b</td>
<td>3.23±0.35b</td>
<td>14.00±0.56b</td>
<td>3.21±0.00b</td>
<td>9.76±0.45b</td>
<td>49.22±0.92b</td>
<td>26.25±0.67b</td>
<td>5.53±0.78abc</td>
<td>8.01±1.05abc</td>
</tr>
<tr>
<td>DFRB 2</td>
<td>68.52±1.43bc</td>
<td>6.13±0.64bc</td>
<td>25.95±1.12bc</td>
<td>3.12±0.01bc</td>
<td>11.64±0.65bc</td>
<td>49.56±1.20bc</td>
<td>37.75±1.46bc</td>
<td>4.46±1.14cd</td>
<td>6.47±1.66cd</td>
</tr>
<tr>
<td>DFRB 4</td>
<td>72.73±1.19cd</td>
<td>5.37±0.31cd</td>
<td>23.88±0.54cd</td>
<td>2.89±0.03cd</td>
<td>14.47±0.83cd</td>
<td>49.59±0.74cd</td>
<td>32.75±1.12cd</td>
<td>4.83±1.01ef</td>
<td>7.16±1.76ef</td>
</tr>
<tr>
<td>Risolubles 0</td>
<td>71.62±1.39de</td>
<td>7.57±0.83de</td>
<td>30.08±1.54de</td>
<td>3.35±0.01de</td>
<td>5.36±0.43de</td>
<td>46.86±1.97de</td>
<td>31.00±2.58de</td>
<td>7.24±1.37ef</td>
<td>9.69±1.97ef</td>
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<td>Risolubles 2</td>
<td>66.75±1.63ef</td>
<td>9.70±1.22ef</td>
<td>31.37±1.61ef</td>
<td>3.57±0.01ef</td>
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<td>46.10±1.34ef</td>
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<td>36.71±1.07gh</td>
<td>3.54±0.03gh</td>
<td>7.19±0.63gh</td>
<td>45.40±1.41gh</td>
<td>29.00±0.74gh</td>
<td>5.10±0.78gh</td>
<td>6.93±0.77gh</td>
</tr>
<tr>
<td>Rifiber 0</td>
<td>80.00±1.75i</td>
<td>2.10±0.39i</td>
<td>14.60±0.72i</td>
<td>3.12±0.09i</td>
<td>10.07±0.60i</td>
<td>48.55±0.35i</td>
<td>38.75±0.45i</td>
<td>4.78±0.42j</td>
<td>5.87±1.05j</td>
</tr>
<tr>
<td>Rifiber 2</td>
<td>66.15±1.76j</td>
<td>6.25±0.62j</td>
<td>26.43±0.97j</td>
<td>2.98±0.06j</td>
<td>12.62±0.70j</td>
<td>48.30±0.67j</td>
<td>41.00±0.74j</td>
<td>4.21±0.69k</td>
<td>6.06±1.64k</td>
</tr>
<tr>
<td>Rifiber 4</td>
<td>73.23±1.48kl</td>
<td>4.37±0.36kl</td>
<td>22.50±0.85kl</td>
<td>2.90±0.01kl</td>
<td>16.15±1.38kl</td>
<td>49.06±1.54kl</td>
<td>44.50±5.80kl</td>
<td>4.98±0.62kl</td>
<td>6.58±0.74kl</td>
</tr>
<tr>
<td>Riban 0</td>
<td>74.02±0.98m</td>
<td>4.57±0.27m</td>
<td>25.13±0.96m</td>
<td>3.28±0.13m</td>
<td>9.28±0.50m</td>
<td>49.11±1.50m</td>
<td>29.00±1.63m</td>
<td>6.95±1.81k</td>
<td>8.97±2.03kn</td>
</tr>
<tr>
<td>Riban 2</td>
<td>79.31±0.47n</td>
<td>3.03±0.20n</td>
<td>19.92±0.67n</td>
<td>3.46±0.01nc</td>
<td>9.63±0.73n</td>
<td>47.78±1.59n</td>
<td>30.00±1.89n</td>
<td>6.76±1.75nb</td>
<td>8.10±1.97nb</td>
</tr>
<tr>
<td>Riban 4</td>
<td>70.77±0.71o</td>
<td>6.90±0.62o</td>
<td>29.37±1.22o</td>
<td>3.43±0.02oc</td>
<td>13.65±1.14o</td>
<td>49.43±1.02o</td>
<td>32.50±5.80o</td>
<td>5.61±0.89o</td>
<td>6.49±0.39o</td>
</tr>
</tbody>
</table>

p-Value | 0.000 | 0.000 | 0.000 | 0.000 | 0.010 | 0.000 | 0.000 | 0.000 | 0.033 |

* Mean values with different letters in same column are significantly different (p < 0.05). DFRB = defatted rice bran. The values of 0, 2 and 4 indicate egg albumen content (%).

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The protein and dietary fibre content of GF breads containing the four different types of rice bran compared to the control bread were determined. All breads were prepared using 2% albumen. Results are presented in Table 4. Protein determination showed that all GF breads had a significantly higher level of protein content than the control bread. Highest protein content was found in bread supplemented with Rifiber (7.5% dm), followed by DFRB, Riban and Risolubles, analogous to the protein content of the rice bran sources (Table 1). As aimed, addition of rice bran to GF breads showed pronounced increment of TDF contents, which again corresponded to the amount of the rice bran sources (Rifiber > Riban > DFRB > Risolubles). The TDF content of the GF breads increased significantly from 2.29% (control) to 5.97% for GF bread containing 10% Rifiber. Compared to the control bread, addition of Risolubles did not increase the content of TDF, which was expected. Analogous to TDF content, IDF content was increased in the range Rifiber > Riban > DFRB > Risolubles = Control bread. Risolubles again showed no significant increase of IDF, but it was increased from 2.19% (control bread) to 5.29% after addition of 10% Rifiber. In contrast, results for SDF could not fully be related to the content in the rice bran source. SDF content of GF bread was significantly increased after addition of Risolubles, Riban and Rifiber, but not after addition of DFRB, although its original content was the same as in Rifiber. But as differences were rather small, it seemed that this result might be related to the reliability of the method for determination of SDF. The
results proved that Ribran, Riber and DFRB were an excellent source for TDF and IDF, while Ribran, Riber and in particular Risolubles were good sources for SDF.

In terms of health benefits, both IDF and SDF have different physiological effects. IDF is mainly related to intestinal regulation and water absorption, whereas SDF is associated with cholesterol lowering and improved diabetic control (Cummings et al., 1997) and to moderate postprandial glycaemic responses (Vergara-Valencia et al., 2007). According to the American Dietetic Association, the current recommended fibre intakes for adults range from 25 to 30 g/day and the IDF-SDF ratio should be 3 (Borderias et al., 2005). Addition of rice bran improved the ratio of IDF-SDF in GF breads, reduction of the ratio was pronounced in the following range: Risolubles (2.7) < Rice bran (6.1) < Riber (9.3) < DFRB (10.1). The IDF-SDF ratio of the control was about 21.5.

The effects of different types of rice bran on the sensory attributes (appearance, colour, odour, taste, texture and overall quality) of GF bread are shown in Table 4. All sensory attributes improved significantly by addition of rice bran when compared to the control, except for texture of GF bread with addition of Risolubles. Highest scores were achieved for appearance, texture and overall impression after addition of Riber, DFRB and Ribran, for colour after addition of DFRB, for smell after addition of Ribran and Riber, and for taste after addition of all four sources of rice bran. These results prove that addition of rice bran not only enhances the physico-chemical and nutritional profile of the final GF breads, it was also preferred by the panelists over the control bread. It has to be mentioned that the panelists were mainly Austrians, who are well used to wholemeal bread or bread containing bran, as in Austria, usual bread consumption is not only based on white (wheat) bread compared to many other countries. But studies in other parts of the world also found that addition of rice bran to (wheat) bread (1–3%) was accepted during sensory evaluations (Hu et al., 2009).

3.4. Shelf life of optimized selected recipes of GF breads with different rice bran sources

GF breads often face the problem of fast staling, as they are mainly based on pure starch ingredients, and thus retrograde faster than breads based on flour (Gallagher et al., 2004). In order to investigate if rice bran addition can improve shelf life, the GF breads with the four different rice bran sources as well as the control were stored at 20°C and 50% RH and tested over a nine-day period. Only after nine days, all breads showed higher crumb firmness than the initial hardest GF bread, which was the one with DFRB addition, and they were then all perceived as being hard. As expected, the crumb firmness for all bread samples significantly increased (p < 0.05) with storage time for all bread samples. To describe the staling rate, the Avrami model was applied, which is widely used for fitting the observed data of bread staling (Armero and Collar, 1998). The values for Avrami kinetic parameters, T<sub>∞</sub> (final crumb firmness), k (rate constant), n (Avrami exponent) and T<sub>0</sub> (crumb firmness of fresh bread) reported in Table 5 allowed to distinguish different staling kinetics for control and rice bran containing breads during storage. Breads without rice bran followed an intermediate staling rate during storage when compared with rice bran containing breads. GF bread supplemented with DFRB showed the highest values for rate constant (k) giving harder breads with faster staling kinetics during storage, while Risolubles stands out for its lowest value for final crumb firmness (T<sub>∞</sub>) and highest value for Avrami exponent (n), respectively. Risolubles blends provided soft initial fresh breads with slower kinetics (k) during storage. This can probably be attributed to the high content of SDF and low content of IDF. Thus, by selecting a rice bran source with high content of SDF, shelf life can be extended notably.

4. Conclusions

Supplementing GF bread with rice bran improved the final bread quality greatly, with darker colour of crust, higher specific volume and softer crumb firmness. The increased dietary fibre enhanced the nutritional profile of the GF breads, which were preferred over the control bread by a sensory panel. Selecting rice brans with high proportion of SDF further improved bread parameters and contributed largely to the extension of shelf life. These studies have clearly demonstrated the potential of selected rice bran fractions for developing high quality GF breads.

References


| Table 4 Nutritional properties (content of protein, TDF, IDF, SDF) and sensory* evaluation. |
|---|---|---|---|---|---|---|---|---|
| Protein (%dm) | TDF (%dm) | SDF (%dm) | IDF (%dm) | Sensory appearance | Sensory colour | Sensory smell | Sensory taste | Sensory texture | Sensory overall impression |
| Control | 5.54 ± 0.387<sup>a</sup> | 2.29 ± 0.36<sup>b</sup> | 0.10 ± 0.06<sup>a</sup> | 2.19 ± 0.42<sup>b</sup> | 4.42 ± 2.282<sup>c</sup> | 3.75 ± 2.455<sup>c</sup> | 3.66 ± 1.885<sup>c</sup> | 3.92 ± 2.257<sup>c</sup> | 5.40 ± 2.386<sup>c</sup> | 3.59 ± 1.856<sup>c</sup> |
| Risolubles | 6.08 ± 0.119<sup>b</sup> | 2.46 ± 0.26<sup>b</sup> | 0.16 ± 0.19<sup>a</sup> | 1.80 ± 0.44<sup>a</sup> | 5.89 ± 2.111<sup>c</sup> | 6.59 ± 2.322<sup>b</sup> | 6.28 ± 1.699<sup>b</sup> | 6.78 ± 1.877<sup>b</sup> | 6.24 ± 1.883<sup>b</sup> | 5.89 ± 1.792<sup>b</sup> |
| Riber | 5.78 ± 0.014<sup>b</sup> | 1.97 ± 0.28<sup>b</sup> | 0.18 ± 0.16<sup>b</sup> | 1.93 ± 0.40<sup>b</sup> | 7.33 ± 1.096<sup>c</sup> | 6.95 ± 1.142<sup>b</sup> | 6.72 ± 1.395<sup>b</sup> | 6.41 ± 1.935<sup>b</sup> | 6.79 ± 1.561<sup>b</sup> | 7.11 ± 1.279<sup>b</sup> |
| DFRB | 6.97 ± 0.007<sup>c</sup> | 4.44 ± 0.45<sup>c</sup> | 0.40 ± 0.05<sup>b</sup> | 4.05 ± 0.42<sup>b</sup> | 7.71 ± 1.277<sup>c</sup> | 7.74 ± 1.166<sup>c</sup> | 6.90 ± 2.158<sup>c</sup> | 6.29 ± 1.582<sup>b</sup> | 7.27 ± 1.599<sup>b</sup> | 7.11 ± 1.770<sup>b</sup> |
| Ribran | 6.73 ± 0.021<sup>c</sup> | 5.03 ± 0.43<sup>c</sup> | 0.71 ± 0.25<sup>c</sup> | 4.32 ± 0.20<sup>b</sup> | 6.81 ± 1.569<sup>c</sup> | 6.74 ± 1.596<sup>b</sup> | 7.07 ± 1.681<sup>c</sup> | 6.79 ± 1.865<sup>b</sup> | 7.69 ± 1.415<sup>c</sup> | 6.89 ± 1.555<sup>c</sup> |

* Mean values with different letters in same column are significantly different (p < 0.05).

| Table 5 Staling kinetic parameters (firmness N) during 9-day storage of GF breads fitted to the Avrami equation. |
|---|---|---|---|---|---|
| Sample | T<sub>∞</sub> (N) | T<sub>f</sub> (N) | n | k | Adj. R<sup>2</sup> |
| Control | 12.34 | 35.76 | 1.863 | 0.055 | 0.982 |
| DFRB | 14.21 | 35.62 | 1.797 | 0.061 | 0.965 |
| Risolubles | 6.42 | 18.34 | 2.312 | 0.014 | 0.911 |
| Riber | 13.49 | 29.72 | 1.852 | 0.053 | 0.979 |
| Ribran | 10.00 | 23.81 | 1.776 | 0.059 | 0.969 |


