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Dietary fibre sources in bread: Influence on technological quality

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ABSTRACT

The Response Surface Methodology was employed to study the effects of adding different dietary fibre sources (wheat bran, resistant starch and locust bean gum), on process and quality parameters of pan bread. The experiments were carried out according to a 2^3 central composite rotational design (CCRD). With the experimental results or responses, the effect of each variable was calculated and the interactions between them were determined. For some parameters, such as proofing time, crust colour acceptance, crust appearance acceptance, taste acceptance and aroma acceptance, fibre addition did not present a significant effect. For the remaining parameters evaluated, it was possible to establish a mathematical model to explain the effect of the different dietary fibre sources. High-speed mixing time, crumb colour acceptance, crumb appearance acceptance and texture acceptance were influenced by the three different fibre sources studied. Wheat bran was the only fibre source that influenced specific volume and crumb chroma and hue angle. Wheat bran and locust bean gum (LBG) contributed to retain moisture in the crumb during all the storage period.

1. Introduction

Fibre is an important component of diet and nutrition. Generally speaking, dietary fibre is the edible parts of plants, or similar carbohydrates, that are resistant to digestion and absorption in the small intestine (Lattimer & Haub, 2010). There are many beneficial effects of increased dietary fibre consumption on human health and body function (Dreher, 2001).

Dietary fibre can belong to the following categories: (i) edible carbohydrate polymers naturally occurring in the food as consumed; (ii) carbohydrate polymers, which have been obtained from food raw material by physical, enzymic or chemical means and which have been shown to have a physiological effect of benefit to health as demonstrated by generally accepted scientific evidence to competent authorities; and (iii) synthetic carbohydrate polymers which have been shown to have a physiological effect of benefit to health as demonstrated by generally accepted scientific evidence to competent authorities (Phillips & Cui, 2011).

Traditionally, consumers have chosen foods such as whole grains, fruits and vegetables as sources of dietary fibre. Recently, food manufacturers have responded to consumer demands for foods with higher fibre content by developing products in which high-fibre ingredients are used (Nelson, 2001). Focus on the development of tasty, health-promoting food options that are rich in cereal grains and fibres are needed to adequately offer the benefits of fibre to consumers (McCleary, 2011).

Wheat is the most important cereal crop in the world and wheat bran (WB) is the major by-product of the wheat industry (Manisseri & Gudipati, 2010). The bran amounts to approximately 12–15% of the grain. Many benefits are associated to the consumption of WB, such as reducing the risk of certain types of cancer; promoting positive health effects on the gastrointestinal tract, decreasing intestinal transit time and increasing fecal bulk and stool number; preventing and treating constipation; treating diverticulosis and irritable bowel syndrome; reducing the risk for obesity and assisting in weight maintenance; protecting against gallstone formation; and affording significant benefits to diabetics, by improving glycemic control and reducing the requirements for insulin and/or oral hypoglycemic agents (Cho & Clark, 2001).

The portion of starch and starch products that resists digestion in the small intestine has been described as resistant starch (RS). Starch may become resistant to digestion due to several reasons, as it may be physically inaccessible (RS1), compact granular structure (RS2), retrograded or crystalline non-granular (RS3), chemically modified or re-polymerized (RS4) or amylose-lipid complexed (RS5) starches. RS may be categorized as a functional dietary fibre, as defined by the American Association of Cereal Chemists and Food and Nutrition Board of the Institute of Medicine of the National Academics (Fuentes-Zaragoza et al., 2011; Sharma, Yadav, & Ritika, 2008). It almost entirely passes the small intestine and it can behave as a substrate for growth of probiotic microorganisms

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(Sajilata, Singhal, & Kulkarni, 2006). RS, such as high-amylose starch (RS2), is a prebiotic. The metabolic products, especially short-chain fatty acids (SCFA), have emerged as important metabolic fuels for colonocytes, as well as having specific actions that promote normal colonic function (Topping et al., 2003).

In general, literature has reported various detrimental effects on dough handling and bread quality associated with flour replacement by dietary fibre (Angioloni & Collar, 2008), such as WB and RS. Locust bean gum (LBG) is a hydrocolloid that has demonstrated good results for increasing the technological quality of baked goods (Sharadanant & Khan, 2003a, 2003b), and it could be useful in breads with added WB and RS. Moreover, LBG is also considered a dietary fibre, among substances that encompass health benefits and significantly reduce the risk of many human disorders (Redgwell & Fischer, 2005).

In our previous work (Almeida, Chang, & Steel, 2010), we studied the effect of the addition of these dietary fibres on the farinographic properties of wheat flour. It was verified that the fibres studied altered the main farinographic parameters drastically, suggesting that the incorporation of these fibres in breadmaking processes leads to various consequences to the dough forming stage (mixing) which must be considered for the adjustment of process parameters. These results suggested that there are also changes in other process parameters and in bread quality characteristics. Thus, the objective of this work was to evaluate the influence of the addition of dietary fibre sources on various breadmaking process parameters and pan bread quality characteristics through the Response Surface Methodology.

2. Material and methods

2.1. Material

The material used was kindly donated by suppliers. The wheat flour used was wheat flour for breadmaking Letizia® (Cargill Agrícola S.A., Tatuí, Brazil). It present moisture, proteins (N × 5.7), lipids and ash contents of 10.22 ± 0.08 g/100 g, 11.86 ± 0.13 g/100 g, 1.08 ± 0.02 g/100 g and 0.55 ± 0.04 g/100 g, respectively. Its wet gluten, dry gluten and gluten index were 30.90 ± 0.42 g/100 g, 10.25 ± 0.21 g/100 g and 75.67 ± 9.03 g/100 g, respectively, and its Falling Number was 358 ± 6 s.

The sources of dietary fibre used were: wheat bran (WB) – toasted coarse wheat fibre (Bonali Alimentos Ltda., Cruzeiro, Brazil), granular RS2-type corn resistant starch (RS) – Hi-Maize® 260 (National Starch and Chemical Industrial Ltda., São Paulo, Brazil) and locust bean gum (LBG) – Grindsted® LBG 147 (Danisco Brazil Ltda., Cotia, Brazil).

Characterization of the dietary fibre sources used can be found in Almeida et al. (2010). Dietary fibre contents were 47.22%, 37.98% and 82.14%; water absorption index (WAI) was 6.33, 2.32 and 13.69; and water solubility index (WSI) was 12.20%, 0.98% and 0%, for WB, RS and LBG, respectively.

2.2. Methods

2.2.1. Bread production

The formulation used in this work was: wheat flour (100 g), instant baker's yeast (1.7 g), salt (1.5 g), sugar (4.0 g), hydrogenated vegetable fat Fatgill PF 38 EXP Cargill (4.0 g), vital gluten Roquette Frères (4.0 g); emulsifier diacetylated tartaric acid ester with mono and diglycerides (DATEM) Panodan® ALB 10 Danisco (0.30 g); fungal α-amylase 10.000 SKB Grindamyl™ A1000 Danisco (0.008 g) and ascorbic acid DSM (0.01 g). The amount of water added to each formulation varied according to the farinographic water absorption determined previously (Almeida et al., 2010). The combinations of WB, RS and LBG were added to the formulation (in percentages flour basis) according to a complete factorial experimental design. Eighteen assays were conducted, being eight factorial points (2^3), six axial points (2 × 3), and four repetitions of the central point (Table 1). Six assays were carried out per day, with one of the central points included. The ranges of the concentrations (flour basis) of the different fibres used were: 0–20 g WB/100 g flour, 0–20 g RS/100 g flour and 0–3 g LBG/100 g flour.

For each formulation, the ingredients were mixed in an automatic spiral mixer, model HAE 10 (Hypo, Ferraz de Vasconcelos, Brazil), during 4 min on low speed (with addition of fat and DATEM at the end) and during the time necessary for complete gluten development on high speed. Cool water was added and dough final temperature was monitored so as not to exceed 29 °C. Immediately after mixing, dough was divided into portions of 175 ± 1 g and left to rest during 15 min in a proofing chamber, model 20B (Klimaquip,

Table 1
Proofing time and scores of the sensory acceptance and purchase intention tests of the breads prepared with combinations of wheat flour and different dietary fibre sources.

Assays	WB	RS	LBG	Proofing time (min)	Sensory acceptance[a]				% positive purchase intention[b]
					Crust colour	Crust appearance	Aroma	Taste	
1	−1 (4)	−1 (4)	−1 (0.3)	90	7.0 ± 1.7	6.7 ± 1.7	6.6 ± 1.6	6.2 ± 1.9	29.4
2	+1 (16)	−1 (4)	−1 (0.3)	107	7.7 ± 0.9	7.3 ± 0.9	7.2 ± 1.3	7.2 ± 1.2	77.8
3	−1 (4)	+1 (16)	−1 (0.3)	133	7.6 ± 1.1	7.5 ± 1.1	7.3 ± 1.3	6.8 ± 1.5	56.7
4	+1 (16)	+1 (16)	−1 (0.3)	122	7.3 ± 1.2	7.2 ± 1.3	7.4 ± 1.3	6.7 ± 1.4	55.9
5	−1 (4)	−1 (4)	+1 (2.4)	92	7.6 ± 1.3	7.5 ± 1.2	7.2 ± 1.2	7.3 ± 1.3	70.0
6	+1 (16)	−1 (4)	+1 (2.4)	108	7.5 ± 1.2	7.3 ± 1.5	7.4 ± 1.1	6.8 ± 1.3	76.5
7	−1 (4)	+1 (16)	+1 (2.4)	130	7.5 ± 0.9	7.4 ± 1.1	7.0 ± 1.1	7.0 ± 1.3	63.3
8	+1 (16)	+1 (16)	+1 (2.4)	118	7.3 ± 1.1	6.8 ± 0.9	7.3 ± 1.3	6.6 ± 1.5	55.6
9	−1.68 (0)	0 (10)	0 (1.5)	105	7.2 ± 1.4	7.2 ± 1.4	7.1 ± 1.3	6.6 ± 1.8	46.7
10	+1.68 (20)	0 (10)	0 (1.5)	112	7.2 ± 1.5	7.1 ± 1.7	7.2 ± 1.2	6.8 ± 1.5	58.8
11	0 (10)	−1.68 (0)	0 (1.5)	98	7.7 ± 1.0	7.1 ± 1.4	7.1 ± 1.4	7.1 ± 1.1	72.2
12	0 (10)	+1.68 (20)	0 (1.5)	92	7.7 ± 0.9	7.6 ± 1.3	7.1 ± 1.0	7.1 ± 1.4	63.3
13	0 (10)	0 (10)	−1.68 (0)	92	7.8 ± 0.9	7.2 ± 1.3	7.3 ± 1.2	7.0 ± 1.7	63.9
14	0 (10)	0 (10)	+1.68 (3.0)	113	7.5 ± 0.9	7.4 ± 1.1	7.3 ± 1.3	6.7 ± 1.3	64.7
15	0 (10)	0 (10)	0 (1.5)	108	7.8 ± 0.8	7.2 ± 1.3	7.5 ± 1.3	6.8 ± 1.8	63.9
16	0 (10)	0 (10)	0 (1.5)	97	7.6 ± 1.0	7.5 ± 1.0	6.9 ± 1.6	6.9 ± 1.3	64.7
17	0 (10)	0 (10)	0 (1.5)	90	7.4 ± 1.3	7.1 ± 1.5	7.2 ± 1.2	6.9 ± 1.5	60.0
18	0 (10)	0 (10)	0 (1.5)	113	7.4 ± 1.2	7.0 ± 1.4	7.3 ± 1.4	6.6 ± 1.7	58.3

*Mean ± standard deviation, $n = 30$. WB = wheat bran; RS = resistant starch and LBG = locust bean gum. Values in brackets refer to concentrations (g/100 g flour) of WB, RS and LBG.

[a] Hedonic scale ranging from 1 = "disliked extremely" to 9 = "liked extremely".

[b] Panellist who attributed scores from 4 to 5 (in a scale from 1 = "would certainly not buy" to 5 = "would certainly buy") were considered.

Pouso Alegre, Brazil), at 30 °C and 80% RH. After this time, doughs were moulded into cylinders, put in baking pans (18 × 6.5 × 5 cm) and left to proof in the proofing chamber at 30 °C and 80% RH, until the geometric centre of the dough reached a height of 1.5 cm above the edge of the baking tin. Proofing time for each formulation was monitored. Loaves were baked during 40 min at 160 °C in a hearth oven, model HF 4B (Hypo, Ferraz de Vasconcelos, Brazil), with vapour injection in the first instants of baking. One hour after removing the loaves from the oven, they were packaged in polypropylene bags.

2.2.2. *Evaluation of bread quality characteristics*

Loaf apparent volume was determined by seed displacement, and loaf mass, using a semi-analytical scale. Specific volume was determined through the volume/mass ratio and expressed in mL/g. Specific volume was determined in triplicate, 1 h after baking.

Crumb colour was determined instrumentally, using a Color Quest II colorimeter (Minolta Camera Co., Osaka, Japan). Established parameters were: observation angle 10° and illuminant D65. Values of L* or lightness (black 0/white 100), a* (green−/red+) and b* (blue−/yellow+), also referred to as the CIE Lab colour system, were determined, and values of C* or chroma and h* or hue angle, also referred to as the CIE L*C*h colour space, were calculated according to Equations (1) and (2) (Minolta, 1993). Crumb colour evaluation was made in the centre of the 4 central slices of the loaf. All measurements were carried out in triplicate.

$$\text{Chroma}\left(C^*\right) = \left(\left(a^*\right)^2 + \left(b^*\right)^2\right)^{1/2} \tag{1}$$

$$\text{Hue angle}(h_{ab}) = \tan^{-1}\left(b^*/a^*\right) \tag{2}$$

Bread sensory evaluation was carried out two days after baking, through acceptance and purchase intention tests. Thirty non-trained panellists evaluated the samples using a 9-point hedonic scale (Stone & Sidel, 1993), with 1 = “disliked extremely” and 9 = “liked extremely” for the acceptance tests. Panellists evaluated the samples in individual cabins, under a white light. Six samples were presented monadically. The attributes evaluated were: crust colour, crumb colour, crust appearance, crumb appearance, aroma, taste and texture. Panellists also expressed their purchase intention through a 5-point scale that varied from 1 = “would certainly not buy” to 5 = “would certainly buy”. Positive purchase intention was calculated as the percentage of panellist who attributed scores from 4 to 5. A profile of the panellists was obtained, regarding fibre-enriched bread consumption frequency. Bread quality during storage was evaluated through moisture analysis on days 1, 4 and 7 after baking. Crumb moisture was determined in triplicate through AACC Method 44-40.01 (AACC, 2010).

2.3. *Statistical analysis*

The responses obtained for the assays carried out according to the central composite rotational design (CCRD) used to study the effects of the independent variables (WB, RS and LBG) were analysed using the Statistica 5.0 software (Statsoft Inc., Tulsa, USA), permitting analysis through the Response Surface Methodology, according to Rodrigues and Iemma (2005). The responses or dependent variables were the process parameters (high-speed mixing time and proofing time) and the bread quality characteristics (specific volume, crumb instrumental colour through L*, C* and h, sensory analysis through the acceptance and purchase intention tests and moisture during storage). When mathematical models were obtained to explain these responses, they must be used with coded values for the independent variables, where: WB = coded value ($-\alpha$ to $+\alpha$) of concentration of wheat bran; RS = coded value ($-\alpha$ to $+\alpha$) of concentration of resistant starch; LBG = coded value ($-\alpha$ to $+\alpha$) of concentration of locust bean gum; Fcalc = calculated F; Ftab = tabled F.

3. Results and discussion

3.1. *High-speed mixing time*

High-speed mixing times necessary to reach maximum gluten network development for each of the experimental design assay doughs varied between 1.32 min and 3.18 min. This variation could be due to the variation of the quantity and type of fibre present, which directly affected the amount of water added to the dough and the form this water was absorbed or left available for the development of the gluten network. The increase of viscosity can also be one of the factors involved in the modification of high-speed mixing time.

A mathematical model to describe the behaviour of high-speed mixing time as a function of the quantity of the different dietary fibre sources added, within the ranges studied, was obtained (Equation (3)). Through this model, it can be verified that the three sources of dietary fibre used had a significant effect on this response. Through the response surfaces of the model for high-speed mixing time (Fig. 1), it can be observed that the increase of added WB contributed to increase this response, which is in accordance with literature reports. A region of minimum high-speed mixing time was obtained in our study, constituted of concentrations of RS from 4 to 16 g/100 g flour and LBG higher than 2.4 g/100 g flour, when WB addition was fixed at 10 g/100 g flour.

$$\text{High}-\text{speed mixing time} = 2.05 + 0.59\text{WB} + 0.18\text{RS}^2 - 0.19\text{LBG}$$
$$(r^2 = 0.8897; \text{Fcalc/Ftab} = 11.28) \tag{3}$$

Comparing the results obtained for high-speed mixing time with those obtained for the farinographic parameter dough development time (DDT) in our previous work (Almeida et al., 2010), it is observed that the farinographic parameter helps in showing a tendency of what occurs with the time necessary to reach maximum gluten development in the mixing step of the real breadmaking process (end of dough development in the mixer), but it was not precise. This may be due to the fact that other ingredients and additives, such as sugar, fat and emulsifier, are added in the breadmaking process. With respect to WB, it was noted that this fibre source presented the same behaviour for high-speed mixing time and DDT (increase in concentration, increase in time). RS showed a slight trend to reduce DDT and had little effect on high-speed mixing time. LBG was the fibre source that presented an opposite effect for each of these variables: the increase in concentration increased DDT, but reduced high-speed mixing time.

3.2. *Proofing time*

Dough proofing time was between 90 and 130 min. For this parameter (Table 1), fibre addition did not present a significant effect. With the values obtained, it was not possible to establish a mathematical model for this response as a function of the three dietary fibre sources studied. No linear, quadratic or interaction effect was significant ($p < 0.05$). This indicates that none of the dietary fibre sources used interfered, that is, independently of the amounts of added WB, RS and LBG, the parameter was within the range of the mean value and its standard deviation. This result was not expected. According to Katina (2003), fibre addition tends to increase final proofing time. Wang, Rosell, and Barber (2002) verified that LBG contributed to extend proofing time.

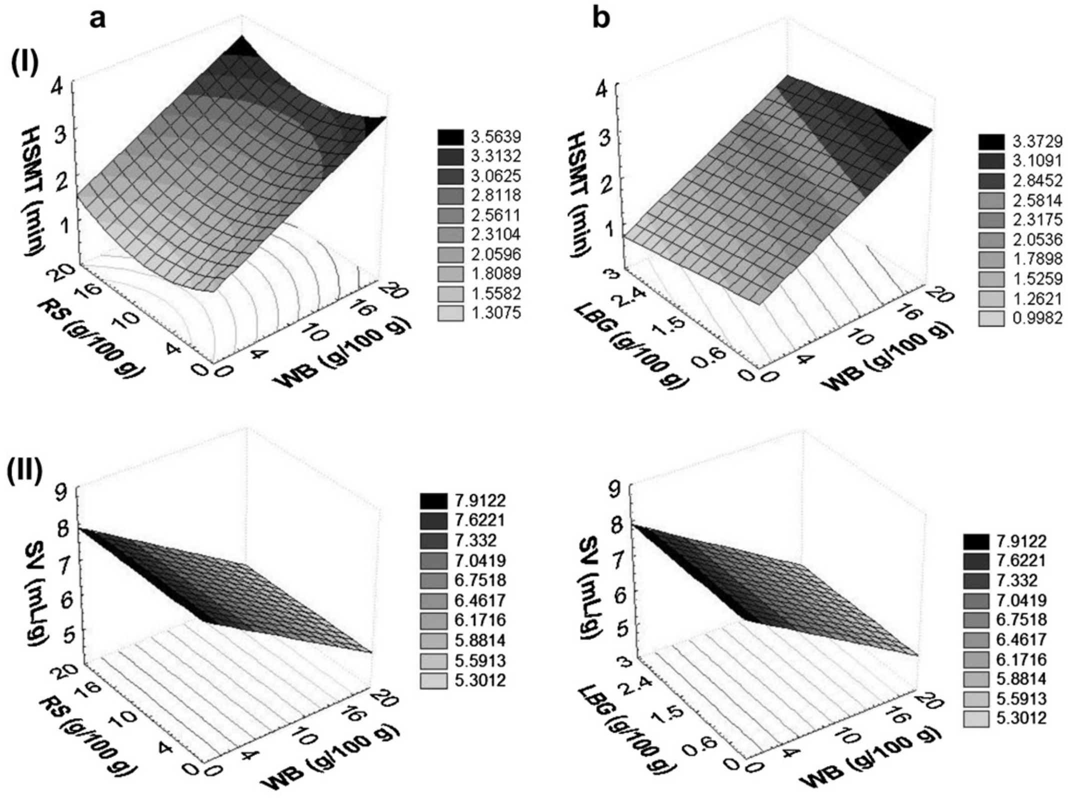

Fig. 1. Response surfaces for (I) high-speed mixing time of doughs and (II) specific volume of breads prepared with combinations of doughs prepared with combinations of wheat flour and different dietary fibre sources, as a function of: (a) WB and RS and (b) WB and LBG, being the third variable fixed at level 0. SV = specific volume; WB = wheat bran; RS = resistant starch and LBG = locust bean gum.

3.3. *Specific volume*

The results for loaf specific volume, according to the experimental design used varied from 5.39 to 8.15 mL/g. Maximum and minimum values occurred for the axial points of the design (Assays 09 and 10, respectively), for which minimum and maximum WB percentages within the range studied were used, simultaneously with intermediate amounts of the other two fibre sources. WB was the only fibre source studied that had a statistically significant effect on specific volume, within the ranges studied. RS and LBG did not affect this response. This can be observed through Equation (4), which is the model that explains the variation of specific volume. Through the analysis of the response surfaces obtained from the model (Fig. 1), it can be seen that the greater the amount of added WB, the lower the specific volume.

$$\text{Specific volume} = 6.46 - 0.86\text{WB} \quad (r^2 = 0.7193;\ \text{Fcalc/Ftab} = 9.13) \tag{4}$$

The negative effect of WB on bread specific volume was also observed in other studies. Kock, Taylor, and Taylor (1999) concluded that WB exerts physical and chemical effects that result in the reduction of bread specific volume. However, Gan, Ellis, and Schofield (1995) report that the physical effect is greater than the chemical effect, while Noort, Van Haaster, Hemery, Schols, and Hamer (2010) mention that the chemical effect is greater than the physical effect.

Although bread specific volume reduction by WB was expected, the non-interference of RS was not. It is known that native starch is an ingredient used to reduce wheat flour strength. When added to bread formulations, specific volume decreases due to the effect of gluten dilution by this ingredient. As RS was used even in high concentrations (up to 20 g/100 g flour) in this study, it was expected that this source of dietary fibre would have an effect, at least due to dilution. However, we found that this fibre source did not have an effect on specific volume, and so did Ozturk, Koksel, and Ng (2009). Loaf volume values of Hylon VII-supplemented breads (granular type-2 RS) did not show significant differences as the addition level increased up to the 20 g/100 g supplementation level, in relation to the bread without supplementation. Reduction of specific volume was only observed with concentrations above 20 g/100 g.

The non-interference of LBG on bread specific volume observed in this study was also verified by Ribotta, Ausar, Beltramo, and León (2005) and by Wang et al. (2002). It may also be due to the lower concentrations used (up to 3 g/100 g flour).

3.4. *Crumb instrumental colour*

For all the colour parameters of pan breads (crumb lightness L*, chroma C* and hue angle h), as expected, it was verified that WB was the fibre source that had a greatest effect, due to its inherent colour (Equations (5)–(7)). The increase in WB reduced lightness and hue angle and increased chroma, that is, made crumb colour darker, with a more saturated colour, tending more to red (Fig. 2). In the studies of Basman and Köksel (1999; 2001), WB also contributed to reduce L* value.

$$\text{Crumb } L^* = 67.19 - 4.11\text{WB} - 1.00\text{LBG} \quad (r^2 = 0.9812;\ \text{Fcalc/Ftab} = 106.38) \tag{5}$$

$$\text{Crumb } C^* = 15.66 + 1.04\text{WB} \quad (r^2 = 0.8871;\ \text{Fcalc/Ftab} = 28.00) \tag{6}$$

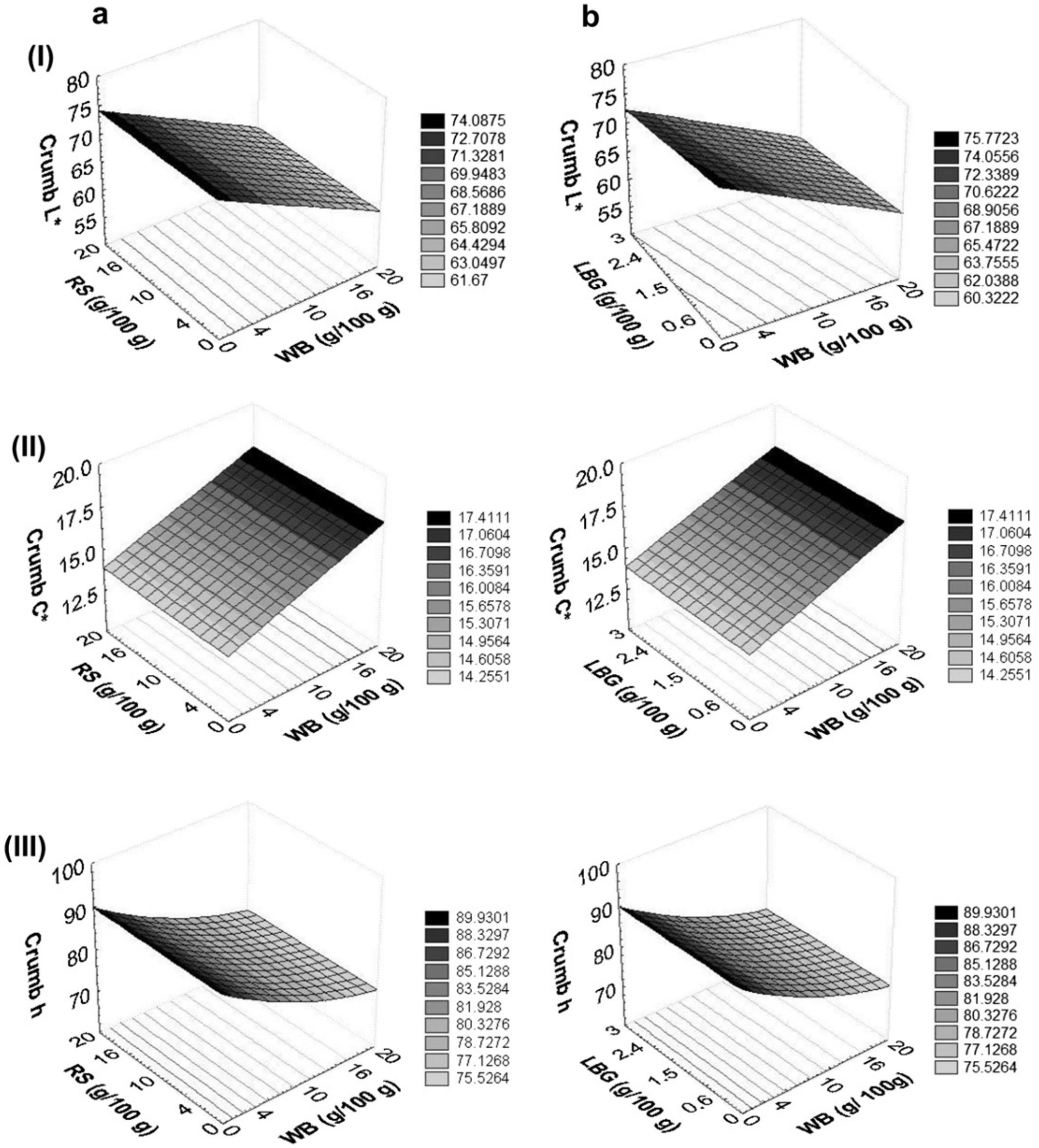

Fig. 2. Response surfaces for (I) crumb L*, (II) crumb C* and (III) crumb h of breads prepared with combinations of wheat flour and different dietary fibre sources, as a function of: (a) WB and RS and (b) WB and LBG, being the third variable fixed at level 0. WB = wheat bran; RS = resistant starch and LBG = locust bean gum.

$$\text{Crumb h} = 79.65 - 4.76\text{WB} + 0.81\text{WB}^2 \quad (r^2 = 0.9870; \text{Fcalc/Ftab} = 155.39) \tag{7}$$

RS and LBG, considered white fibre sources, interfered less with crumb colour. In general, white or clear fibres promote crust and crumb colours very similar to bread without the addition of fibres (Gómez, Ronda, Blanco, Caballero, & Apesteguía, 2003). RS did not interfere with any of the colour parameters. LBG only reduced lightness, not having an effect on the other colour parameters. This crumb lightness reduction could be related to the effect of this fibre source on crumb moisture content (greater moisture, lower lightness). In general, as it would be expected, crumb colour was affected by the colour characteristics of the dietary fibre included in the formulation (Angioloni & Collar, 2011).

3.5. Sensory evaluation

A consumer profile of the panellists who evaluated the breads was defined. It was observed that most of the panellists that evaluated the fibre-enriched breads presented a high consumption frequency of this type of product. As many as 44.7% declared consuming fibre-enriched bread more than once a week; 15.9%, once a week; 21.1%, once every fifteen days; 2.9%, once a month; and 15.4%, occasionally.

Table 1 presents the scores for the parameters crust colour acceptance, crust appearance acceptance, aroma acceptance and taste acceptance, for which fibre addition did not present a significant effect. With the values obtained, it was not possible to establish mathematical models for these responses as a function of the three dietary fibre sources studied. No linear, quadratic or interaction effect was significant ($p < 0.05$). This indicates that none of the dietary fibre sources used interfered, that is, independently of the amounts of added WB, RS and LBG, the parameter was within the range of the mean value and its standard deviation.

For the attributes crumb colour acceptance and crumb appearance acceptance, all three fibre sources had similar effects (Equations (8) and (9)). RS and LBG had little influence, while greater additions of WB made panellists express greater acceptance for these sensory attributes (Fig. 3). However, works found in literature show results opposite to these. The difference in this result could be related to the fact that the panellists that evaluated the samples were frequent consumers of fibre-enriched bread.

$$\text{Crumb colour acceptance score} = 7.55 + 0.20\text{WB} - 0.27\text{WB}^2 + 0.15\text{RS} - 0.18\text{WB RS} - 0.29\text{WB LBG} \quad (r^2 = 0.7477; \text{Fcalc/Ftab} = 2.29) \tag{8}$$

$$\text{Crumb appearance acceptance score} = 7.44 + 0.14\text{WB} - 0.23\text{WB}^2 - 0.15\text{WB RS} - 0.14\text{WB LBG} - 0.19\text{RS LBG} \quad (r^2 = 0.7233; \text{Fcalc/Ftab} = 3.12) \tag{9}$$

The analysis of the response surfaces for the acceptance of crumb appearance and of those for the acceptance of crumb colour (Fig. 2), confirm the comments registered by the consumers in the evaluation forms. It was observed that, when consuming a fibre-enriched bread, they expect to visualize them in the product. As LBG and RS are light and fine fibre sources, WB is the main dietary fibre source responsible for changes in the aspect and colour of the crumbs of breads, as it is constituted by darker and larger particles. This last statement can be confirmed through the evaluation of breads from Assay 9, without WB addition. Consumers, through their comments, questioned the fact that a "white" bread was being presented in an evaluation of fibre-enriched bread. Even the though the form contained the information that they were evaluating a fibre-enriched bread, they contested this information or indicated that that crumb aspect and colour were not expected for the product or, affirmed that the bread was very similar to a bread without fibre addition. Therefore, the crumbs of the breads with greater concentrations of WB were better evaluated, both regarding appearance and colour. Additions above 10 g/100 g flour proportioned good results in the sensory evaluation of crumb appearance and colour of breads.

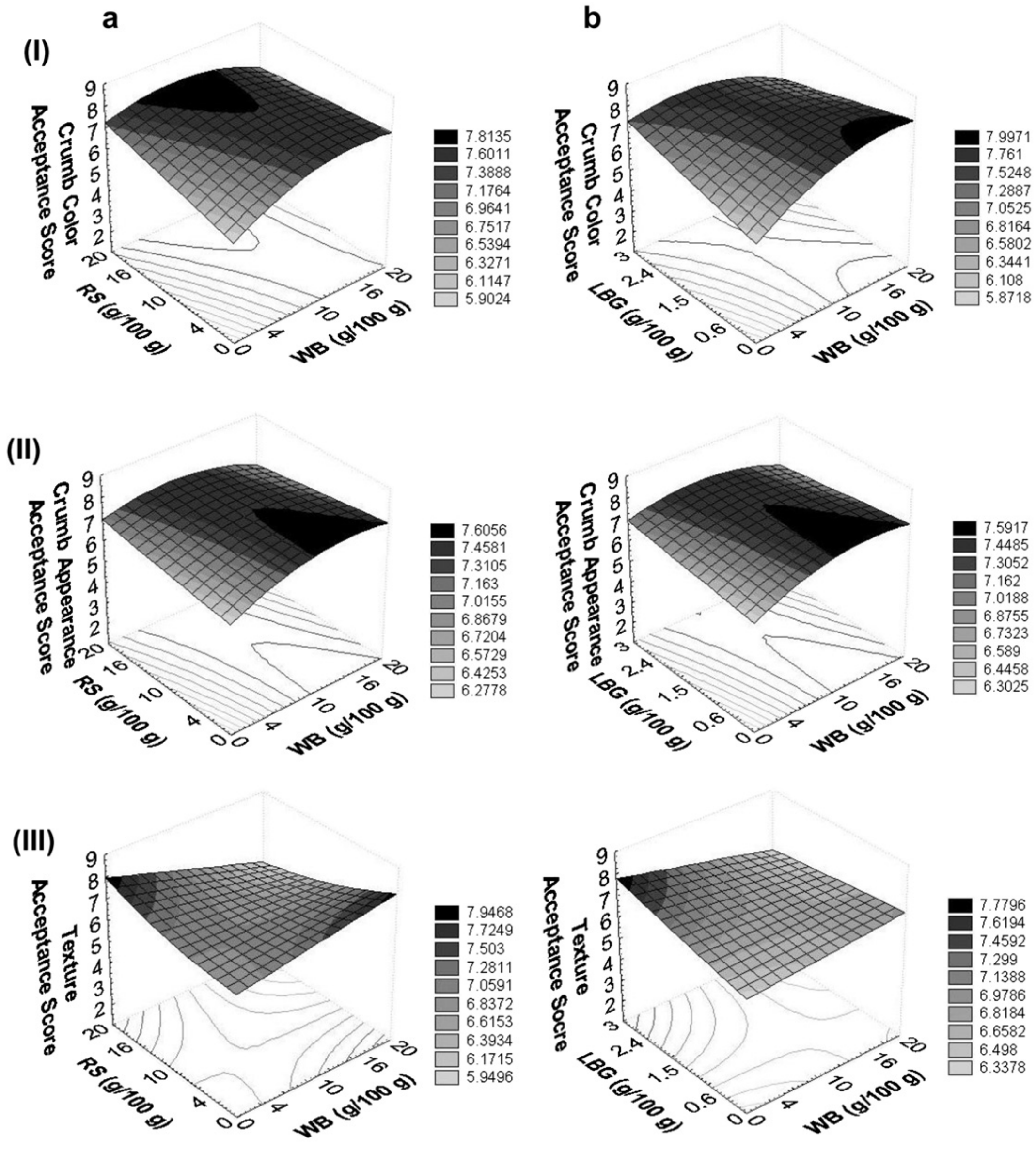

Fig. 3. Response surfaces for (I) crumb colour acceptance score, (II) crumb appearance acceptance score and (III) texture acceptance score of breads prepared with combinations of wheat flour and different dietary fibre sources, as a function of: (a) WB and RS and (b) WB and LBG, being the third variable fixed at level 0. WB = wheat bran; RS = resistant starch and LBG = locust bean gum. *Z* axis: hedonic scale ranging from 1 = "disliked extremely" to 9 = "liked extremely".

Comparing the crumb colour acceptance scores with those obtained in the instrumental colour analysis of the crumb, it can be observed that the panellists expressed greater acceptance for crumbs with lower lightness, that is, darker ($L^* < 68$, approximately), higher saturation ($C^* > 15$, approximately) and with lower hue angles, that is, tending more to red ($h < 81°$, approximately).

For texture acceptance, it can be observed that all three dietary fibre sources influenced this attribute (Equation (10)). Texture acceptance was higher when lower levels of WB and resistant RS were added to wheat flour (lower than 4.0 g/100 g flour for both), while for LBG, levels higher than 1.5 g/100 g flour favoured higher scores (Fig. 3). Thus, it can be observed that the breads that obtained higher acceptance scores for crumb colour and appearance, had lower acceptance in terms of texture. The use of WB in higher concentrations (above 10 g/100 g flour) and LBG in lower concentrations (lower than 0.6 g/100 g flour) were positive for crumb colour and appearance and negative for texture, according to consumer evaluation. Nevertheless, the texture of the breads with the lowest scores was not disapproved, once, in average, consumers expressed their acceptance as "liked slightly". Gómez, Jiménez, Ruiz, and Oliete (2011) also observed that WB reduced bread texture acceptance.

$$\begin{aligned}\text{Texture acceptance score} &= 6.77 - 0.15\text{WB} - 0.12\text{RS} + 0.10\text{RS}^2\\ &+ 0.12\text{LBG} - 0.31\text{WB RS} - 0.20\text{WB LBG} - 0.11\text{RS LBG}\\ &(r^2 = 0.7591; \text{Fcalc/Ftab} = 1.43)\end{aligned} \tag{10}$$

Table 1 presents the percentage purchase intention, which shows that, in general, consumers presented a good purchase intention. Through the response surfaces (not shown) generated from the model (Equation (11)) it was observed that the panellists expressed better purchase intention for breads with higher concentrations of WB and LBG. However, when WB concentration is above 16 g/100 g flour, LBG must be in concentrations below

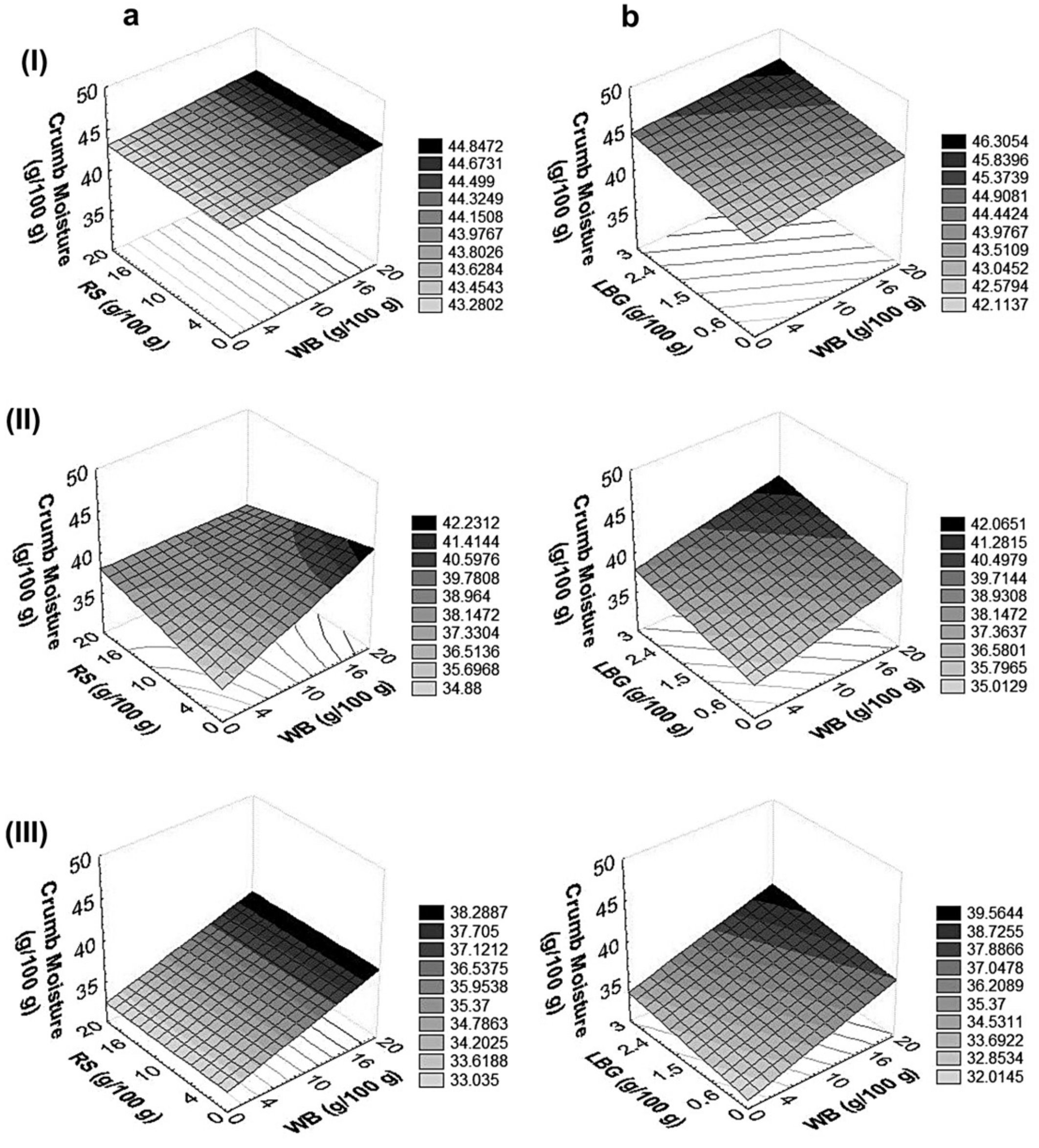

Fig. 4. Response surfaces for crumb moisture content on (I) day 1, (II) day 4 and (III) day 7 of breads prepared with combinations of wheat flour and different dietary fibre sources, as a function of: (a) WB and R and (b) WB and LBG, being the third variable fixed at level 0. WB = wheat bran; RS = resistant starch and LBG = locust bean gum.

1.5 g/100 g flour, for there to be a greater number of panellists with positive purchase intention (and vice-versa).

$$\%\ \text{positive purchase intention} = 64.12 + 4.89\text{WB} - 3.84\text{WB}^2 - 2.72\text{RS} + 3.44\text{LBG} - 7.92\text{WB RS} - 6.11\text{WB LBG} - 4.12\text{RS LBG} \quad (r^2 = 0.8331;\ \text{Fcalc/Ftab} = 2.27) \tag{11}$$

3.6. Crumb moisture

The results of the evaluation of crumb moisture of the breads, one, four and seven days after baking varied from 41.98 g/100 g to 45.78 g/100 g, from 33.92 g/100 g to 41.29 g/100 g and from 31.63 g/100 g to 38.71 g/100 g, respectively. The minimum value of the variation ranges presented for the three days was always that of Assay 1, where all three independent variables were at level −1. The maximum value for crumb moisture on the first day after baking was observed when the highest level of LBG was used (Assay 14). On the other days evaluated, the maximum value for moisture was that of Assay 08, where all the independent variables were at level +1.

Through the response surfaces (Fig. 4) generated from the models (Equations (12)–(14)) it was noted that the fibres added influenced crumb moisture similarly during the storage period. The response surfaces for the three different days were very similar, with practically only a displacement along the *Z* axis (showing the reduction of crumb moisture content during storage). Within the ranges studied, crumb moisture was higher when WB addition was above 10 g/100 g flour and LBG addition above 1.5 g/100 g flour. RS did not interfere with crumb moisture at the beginning and at the end of the storage period. However, on day 4, this fibre source interacted with WB. Crumb moisture can also be related to farinographic water absorption. Moister crumbs were obtained from doughs with higher farinographic water absorptions (WB addition above 10 g/100 g flour and LBG above 1.5 g/100 g flour) (Almeida et al., 2010). Also, the crumbs with greater moisture content one day after baking were the same after seven days.

$$\text{Crumb moisture(day 1)} = 43.98 + 0.52\text{WB} + 0.87\text{LBG} \quad (r^2 = 0.7100;\ \text{Fcalc/Ftab} = 4.99) \tag{12}$$

$$\text{Crumb moisture(day 4)} = 38.15 + 1.22\text{WB} + 1.11\text{LBG} - 0.72\text{WB RS} \quad (r^2 = 0.7288;\ \text{Fcalc/Ftab} = 3.75) \tag{13}$$

$$\text{Crumb moisture(day 7)} = 35.37 + 1.74\text{WB} + 0.76\text{LBG} \quad (r^2 = 0.8104;\ \text{Fcalc/Ftab} = 8.71) \tag{14}$$

The process of bread staling is related to a loss of moisture that could be due to the interaction of polymers that constitute the starch present in wheat flour. Thus, over time, during the shelf-life, RS and LBG could bind to part of the water that is released in the retrogradation process of starch. In bread staling, some water redistribution could occur from one component to another in the crumb (Schiraldi & Fessas, 2001). The WB possibly may not be involved in this process, because the water has already sufficiently linked to its structure. However, the LBG could influence the moisture retention by another mechanism. The stabilization effect of hydrocolloids on starch retrogradation results of their interactions cooperatively in two directions: with water as well as with starch chains in the mixture (Lee, Baek, Cha, Park, & Lim, 2002). The galactomannans could inhibit the process of aggregation of amylose and amylopectin, by acting as a physical barrier preventing self-association of these polymers or by association with aggregated amylose chains (and perhaps also of amylopectin) (Ahmad & Williams, 2001).

4. Conclusion

Through this study, it was possible to verify that, depending on the type and quantity of the dietary fibre source used, different responses can be obtained for process parameters and final quality characteristics of pan bread. Knowing this, fibres can be used by the food technologist in bread formulations, alone or combined, to obtain desired properties such as the increase of dietary fibre content and the maintenance of freshness during shelf-life, or manipulate process parameters such as mixing time. WB and LBG were the fibre sources that most interfered with most of the parameters evaluated. WB reduced specific volume and crumb luminosity and increased high-speed mixing time, crumb chroma and crumb moisture content. LBG also reduced crumb luminosity and increased crumb moisture content, but reduced high-speed mixing time. RS increased high-speed mixing time, but was a more “inert” fibre source in relation to bread quality characteristics, presenting interaction effects with the other fibre sources present in the system. Regarding sensory analyses, the fibre sources studied had effects on the acceptance of crumb colour, crumb appearance and texture and on purchase intention. Many interaction effects between fibre sources were observed. Consumers expected to see bran particles in fibre-enriched breads, thus WB additions above 10 g/100 g flour yielded good results in the sensory evaluation of crumb colour and appearance. Breads with high WB, LBG and RS contents obtained high positive purchase intention percentages. The acceptance of crust colour, crust appearance, aroma and taste was not affected by the addition of the different dietary fibres, within the concentration ranges studied.

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References

AACC. (2010). *International approved methods of analysis*. Method 44–40.01. Available online only. doi:10.1094/AACC IntMethod-44-40.01 (11th ed.). St. Paul: AACC International.

Ahmad, F. B., & Williams, P. A. (2001). Effect of galactomannans on the thermal and rheological properties of sago starch. *Journal of Agricultural and Food Chemistry, 49*, 1578–1586.

Almeida, E. L., Chang, Y. K., & Steel, C. J. (2010). Effect of adding different dietary fiber sources on farinographic parameters of wheat flour. *Cereal Chemistry, 87*, 566–573.

Angioloni, A., & Collar, C. (2008). Functional response of diluted dough matrixes in high-fibre systems: a viscometric and rheological approach. *Food Research International, 41*, 803–812.

Angioloni, A., & Collar, C. (2011). Physicochemical and nutritional properties of reduced-caloric density high-fibre breads. *LWT – Food Science and Technology, 44*, 747–758.

Basman, A., & Köksel, H. (1999). Properties and composition of Turkish flat bread (bazlama) supplemented with barley flour and wheat bran. *Cereal Chemistry, 76*, 506–511.

Basman, A., & Köksel, H. (2001). Effects of barley flour and wheat bran supplementation on the properties and composition of Turkish flat bread (yufka). *European Food Research and Technology, 212*, 198–202.

Cho, S. S., & Clark, C. (2001). Wheat bran. In M. L. Dreher, & S. S. Cho (Eds.), *Handbook of dietary fiber* (pp. 453–472). Boca Raton: CRC Press LLC.

Dreher, M. L. (2001). Dietary fiber overview. In M. L. Dreher, & S. S. Cho (Eds.), *Handbook of dietary fiber* (pp. 1–16). Boca Raton: CRC Press LLC.

Fuentes-Zaragoza, E., Sánchez-Zapata, E., Sendra, E., Sayas, E., Navarro, C., Fernández-López, J., et al. (2011). Resistant starch as prebiotic: a review. *Starch, 63*, 406–415.

Gan, Z., Ellis, P. R., & Schofield, J. D. (1995). Mini review: gas cell stabilisation and gas retention in wheat bread dough. *Journal of Cereal Science, 21*, 215–230.

Gómez, M., Jiménez, S., Ruiz, E., & Oliete, B. (2011). Effect of extruded wheat bran on dough rheology and bread quality. *LWT – Food Science and Technology, 44*, 2231–2237.

Gómez, M., Ronda, F., Blanco, C. A., Caballero, P. A., & Apesteguía, A. (2003). Effect of dietary fibre on dough rheology and bread quality. *European Food Research and Technology, 216*, 51–56.

Katina, K. (2003). High-fibre baking. In S. P. Cauvain (Ed.), *Bread making: Improving quality* (pp. 487–499). Boca Raton: CRC Press LLC.

Kock, S., Taylor, J., & Taylor, J. R. N. (1999). Effect of heat treatment and particle size of different brans on loaf volume of brown bread. *LWT – Food Science and Technology, 32*, 349–356.

Lattimer, J. M., & Haub, M. D. (2010). Effects of dietary fiber and its components on metabolic health. *Nutrients, 2*, 1266–1289.

Lee, M. H., Baek, M. H., Cha, D. S., Park, H. J., & Lim, S. T. (2002). Freeze-thaw stabilization of sweet potato starch gel by polysaccharide gums. *Food Hydrocolloids, 16*, 345–352.

McCleary, B. V. (2011). The evolution of dietary fiber definitions and methods and the role of AACC International. *Cereal Foods World, 56*, 103.

Manisseri, C., & Gudipati, M. (2010). Bioactive xylo-oligosaccharides from wheat bran soluble polysaccharides. *LWT – Food Science and Technology, 43*, 421–430.

Minolta. (1993). *Precise color communication: Color control form feeling to instrumentation*. Osaka: Minolta Camera Co. Ltd.

Nelson, A. L. (2001). *High-fiber ingredients*. St Paul: Eagan Press.

Noort, M. W. J., Van Haaster, D., Hemery, Y., Schols, H. A., & Hamer, R. J. (2010). The effect of particle size of wheat bran fractions on bread quality – evidence for fibre-protein interactions. *Journal of Cereal Science, 52*, 59–64.

Ozturk, S., Koksel, H., & Ng, P. W. (2009). Farinograph properties and bread quality of flours supplemented with resistant starch. *International Journal of Food Sciences and Nutrition, 60*, 449–457.

Phillips, G. O., & Cui, S. W. (2011). An introduction: evolution and finalisation of the regulatory definition of dietary fibre. *Food Hydrocolloids, 25*, 139–143.

Redgwell, R. J., & Fischer, M. (2005). Dietary fiber as a versatile food component: an industrial perspective. *Molecular Nutrition & Food Research, 49*, 521–535.

Ribotta, P. D., Ausar, S. F., Beltramo, D. M., & León, A. E. (2005). Interactions of hydrocolloids and sonicated-gluten proteins. *Food Hydrocolloids, 19*, 93–99.

Rodrigues, M. I., & Iemma, A. F. (2005). *Planejamento de experimentos e otimização de processos: uma estratégia seqüencial de planejamentos*. Campinas: Casa do Pão.

Sajilata, M. G., Singhal, R. S., & Kulkarni, P. R. (2006). Resistant starch: a review. *Comprehensive Reviews in Food Science and Food Safety, 5*, 1–17.

Schiraldi, A., & Fessas, D. (2001). Mechanism of staling: an overview. In P. Chinachoti, & Y. Vodovotz (Eds.), *Bread staling* (pp. 1–18). Boca Raton: CRC Press LLC.

Sharadanant, R., & Khan, K. (2003a). Effect of hydrophilic gums on frozen dough: I. Dough quality. *Cereal Chemistry, 80*, 764–772.

Sharadanant, R., & Khan, K. (2003b). Effect of hydrophilic gums on the quality of frozen dough: II. Bread characteristics. *Cereal Chemistry, 80*, 773–780.

Sharma, A., Yadav, B. S., & Ritika. (2008). Resistant starch: physiological roles and food applications. *Food Reviews International, 24*, 193–234.

Stone, H., & Sidel, J. L. (1993). *Sensory evaluation practices*. San Diego: Academic Press.

Topping, D. L., Morell, M. K., King, R. A., Lib, Z., Bird, A. R., & Noakes, M. (2003). Resistant starch and health – Himalaya 292, a novel barley cultivar to deliver benefits to consumers. *Starch, 55*, 539–545.

Wang, J., Rosell, C. M., & Barber, C. B. (2002). Effect of the addition of different fibres on wheat dough performance and bread quality. *Food Chemistry, 79*, 221–226.