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Evaluation of whole chia (*Salvia hispanica* L.) flour and hydrogenated vegetable fat in pound cake

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ABSTRACT

This study investigated the effects of adding whole chia flour (WCF) on the technological, nutritional and sensory qualities of cakes. Different contents of WCF (0–30 g/100 g flour mixture) and hydrogenated vegetable fat (HVF) (12–20 g/100 g flour mixture) were added to the cake mix based on a 2^2 central composite rotational design. Subsequently, the cake with the best technological results was selected and both the selected cake and the control cake (without WCF) were evaluated for their nutritional and sensory qualities. The results showed that addition of WCF decreased the specific volume and colour parameters of the cakes. The variation in WCF and HVF contents contributed to maintenance of the moisture content during storage. The best technological results were obtained with cakes containing up to 15 g WCF/100 g flour mixture and from 16 to 20 g HVF/100 g flour mixture. The cake formulations containing 15 g WCF/100 g flour mixture and 20 g HVF/100 g flour mixture were selected for further evaluations, and presented higher protein, lipid and ash contents than the control cake. This formulation also exhibited a considerable increase in its omega-3 fatty acid content, good sensory acceptance and a greater purchasing intention.

1. Introduction

Chia (*Salvia hispanica* L.) is an annual summer plant belonging to the *Lamiaceae* family. It was one of the main crops used by pre-Columbian societies in Central America, surpassed only by corn and beans in significance. As such, chia remained a critical ingredient for human consumption in these societies for a long time, but was eventually forgotten on arrival of the Spaniards. In the last decade of the XXth century, chia was revived by a group of scientists and farmers due to its nutritional and functional characteristics (Ayerza & Coates, 2011; Chica, 2011). Chia contains high protein (9–23 g/100 g) (Coates & Ayerza, 1996), dietary fibre (18–41 g/100 g) (Ayerza & Coates, 2000; Bushway, Belya & Bushway, 1981; Reyes-Caudillo Tecante & Valdivia-Lopez, 2008) and lipid (25–35 g/100 g) (Álvarez-Chávez, Valdivia-López, Aburto-Juárez, & Tecante, 2008; Ixtaina et al., 2011; Taga, Miller, & Pratt, 1984) contents. The dietary fibre portion includes lignin, which contains antioxidant compounds and has some hypocholesterolemic effect (Reyes-Caudillo et al., 2008). The lipid fraction contains polyunsaturated fatty acids (PUFAs): omega-3 linolenic acid and omega-6 linoleic acid (Uribe, Perez, Kauil, Rubi & Alcocer, 2011). Chia oil contains the highest known content of α-linolenic fatty acid, up to 67.8 g/100 g, as compared to 36 g/100 g, 53 g/100 g and 57 g/100 g in camelina (*Camelina sativa* L.), perilla (*Perilla frutescens* L.) and flax (*Linum usitatissimum* L.) oils, respectively (Ayerza, 2011). More than 60% of the total fatty acids are omega-3 α-linoleic acid (Chica, 2011). Essential polyunsaturated fatty acids cannot be produced by the human body and must be obtained from the diet. In the human body, α-linolenic acid is the chemical precursor of the longer-chain ω-3 fatty acids, eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (Kislev, Simchoni, Melamed & Maroz, 2011), which have been attributed to health promoting effects (Larsen, Eilertsen & Elvevoll, 2011). Positive health outcomes have been demonstrated in the areas of infant development, cardiovascular disease, platelet aggregation, hypertension, hyperlipidemia, cancer, dementia, Alzheimer's disease, depression and inflammation (McManus, Merga & Newton, 2011). Furthermore, an omega-6/omega-3 ratio of 4:1 or less is recommended. A high ratio of omega-6/omega-3 is detrimental to health and may lead to the development of chronic diseases. Improving the dietary ratio by increasing the omega-3 fatty acids is essential for brain function and for the management of cardiovascular disease, arthritis and cancer (Simopoulos & Cleland, 2003).

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The major market growth for PUFAs in the future appears to be related to increasing the content of PUFAs in the human diet through dietary supplements (Ward & Singh, 2005). Therefore, the incorporation of seeds such as chia in the diet, which contain high contents of these fatty acids, is particularly desirable. However, a major challenge to the development of enriched food products is presented by the multiple acceptance criteria: product freshness, sensory characteristics, appearance, storage conditions, ease of preparation and safety standards, which must be achieved, despite the addition of an active ingredient (Drusch & Mannino, 2009) and nutritional benefits.

Amongst baked goods, bread and cakes are the products with the highest consumption rates (Sozer, Bruins, Dietzel, Franke & Kokini, 2011). Fat or shortening is an important ingredient in a cake formulation because entraps air during the creaming process, physically interferes with the continuity of the starch and protein particles, and emulsifies the liquid in the formulation. In addition, fats and emulsifiers are known to delay gelatinization by delaying the transport of water into the starch granule, due to the formation of complexes between the lipid and amylose during baking. Thus, shortening affects the tenderness, moisture content (Sahin, 2008) and flavour of the cakes.

Cake quality is affected by the balance of the ingredients used, and by the mixing and baking procedures (Tireki, 2008). Most types of cake require fairly high levels of shortening to achieve the characteristic crumb structure (Lakshminarayan, Rathinam & Krishna Rau, 2006). Thus the addition of other substances, such as whole chia flour, can affect the properties of the cake and hence its quality. Therefore, the aim of this paper was to study the effect of incorporating different amounts of whole chia flour and hydrogenated vegetable fat on the technological quality of cakes, and to evaluate the nutritional and sensory characteristics of those cakes that showed the best technological results.

2. Material and methods

2.1. Material

The wheat flour used was wheat flour type 1 (Nita – Moinho Paulista Ltda., Santos, Brazil). The water absorption capacity, stability, mixing tolerance index were 65.3 g/100 g, 10.5 min, 20 BU, respectively, determined through Method 54-21.01 (AACC, 2010); maximum resistance (135 min) and extensibility (135 min) were 900 BU and 128 mm, respectively, determined through Method 54-10.01 (AACC, 2010); and its Falling Number was 547 ± 4 s, determined through Method 56-81.03 (AACC, 2010). Whole chia flour was obtained by milling chia seeds (A. Sturla, Buenos Aires, Argentina) in a laboratory scale mill (Quadrumat Senior Mill, Brabender GmbH & Co. KG, Duisburg, Germany). The hydrogenated vegetable fat used was Pan Advance S550 (Cargill Agrícola S/A, São Paulo, Brazil). The other ingredients were obtained at the local market: sugar (Guarani, Olímpia, Brazil), baking powder (Kraft Foods, Curitiba, Brazil) and whole milk powder (Itambé, Belo Horizonte, Brazil).

2.2. Methods

2.2.1. Physicochemical characteristics of the raw material

The protein, lipid, ash, total fibre, soluble and insoluble fibre contents of the wheat and chia flours were determined by the following AACC methods: 46-13.01, 30-10.01, 08-12.01 and 32-10.01 (AACC, 2010), respectively, and the carbohydrate content calculated by difference. The particle size of the raw materials was determined using AOAC Method 965.22.A (AOAC, 2000) with 8″diameter sieves and 20, 32, 60, 80 and 100 mesh screens.

2.2.2. Cake preparation

The cakes were prepared according to the formulation of Borges, Pirozi, Lucia, Pereira, Moraes and Castro (2006), adding 100 g sugar/100 g flour instead of 86.7/100 g flour. Thus, the basic formulation was the following: flour mixture (wheat flour and whole chia flour) (100 g), sugar (100 g), *in natura* egg (40 g), baking powder (3.3 g) and whole milk powder (11.2 g). The base formulation adopted in this study is a formulation that is typically used in the production of cakes in Brazil. The amounts of whole chia flour (WCF) and hydrogenated vegetable fat (HVF) were established according to a 2^2 central composite rotational design (CCRD) with a total of 11 assays (Rodrigues & Iemma, 2005). The amount of WCF added ranged between 0 and 30 g/100 g flour mixture and the amount of HVF between 12 and 20 g/100 g flour mixture (Table 1). Water was added to hydrate the whole milk powder (75 g water/11.2 g whole milk powder), but the moisture contents of the wheat flour, WCF and whole milk powder were taken into consideration in this calculation, decreasing the amount of water added, since they also contributed water. Thus the water added to the formulations ranged between 60.5 and 60.9 g, according to the assay.

For cake preparation, a cream was initially made as follows: the sugar, eggs and fat were mixed for 2 min at high speed in a K45SS high speed planetary mixer (Kitchenaid, St. Joseph, USA). The wheat flour, whole chia flour, water and whole milk powder were then added to the cream and mixed for 1 min at high speed. Finally the baking powder was added to the batter and mixed for 30 s at

Table 1
Moisture and firmness of the cakes in relation to the amounts of whole chia flour and hydrogenated vegetable fat.

Assay	WCF	HVF	Moisture (g/100 g)			Firmness (N)		
			Day 1	Day 4	Day 7	Day 1	Day 4	Day 7
1	−1 (4.4)	−1 (13.2)	24.55 ± 0.75 aA	25.01 ± 1.01 aA	23.93 ± 0.84 aA	7.10 ± 0.45 C	9.31 ± 0.36 B	10.29 ± 0.30 A
2	+1 (25.6)	−1 (13.2)	24.33 ± 0.31 aA	24.70 ± 0.23 aA	24.15 ± 0.36 aA	7.72 ± 0.57 B	9.20 ± 0.41 A	9.87 ± 0.37 A
3	−1 (4.4)	+1 (18.8)	23.46 ± 0.29 aBA	24.27 ± 0.58 aA	22.36 ± 0.46 aB	5.96 ± 0.26 C	8.25 ± 0.37 B	9.15 ± 0.25 A
4	+1 (25.6)	+1 (18.8)	24.72 ± 0.65 aA	23.99 ± 0.27 aBA	23.05 ± 0.64 aB	6.05 ± 0.11 C	8.34 ± 0.24 B	9.40 ± 0.26 A
5	−1.41 (0)	0 (16)	24.01 ± 0.27 aA	24.53 ± 0.74 aA	22.68 ± 0.29 aB	7.21 ± 0.44 C	9.65 ± 0.30 B	10.49 ± 0.46 A
6	+1.41 (30)	0 (16)	24.44 ± 0.56 aA	23.79 ± 0.57 aA	23.36 ± 0.83 aA	6.58 ± 0.20 C	8.52 ± 0.22 B	9.73 ± 0.80 A
7	0 (15)	−1.41 (12)	24.65 ± 0.12 aA	24.76 ± 0.39 aA	23.19 ± 0.54 aB	8.89 ± 0.32 C	10.29 ± 0.31 B	12.56 ± 0.43 A
8	0 (15)	+1.41 (20)	24.06 ± 0.41 aA	23.64 ± 0.22 aA	22.46 ± 0.24 aB	5.34 ± 0.20 C	7.05 ± 0.24 B	7.82 ± 0.36 A
9	0 (15)	0 (16)	23.90 ± 0.23 aA	24.01 ± 0.38 aA	22.38 ± 0.74 aB	6.16 ± 0.19 C	8.41 ± 0.11 B	8.83 ± 0.26 A
10	0 (15)	0 (16)	24.65 ± 0.62 aA	24.74 ± 0.13 aA	22.85 ± 0.21 aB	6.05 ± 0.17 C	7.57 ± 0.39 B	9.10 ± 0.58 A
11	0 (15)	0 (16)	23.86 ± 0.53 aA	24.08 ± 0.15 aA	22.50 ± 0.57 aB	5.75 ± 0.40 C	7.32 ± 0.27 B	8.32 ± 0.56 A

Mean ± standard deviation, $n = 3$ to 10. WCF = whole chia flour; HVF = hydrogenated vegetable fat. The values in brackets correspond to the amounts of whole chia flour and hydrogenated vegetable fat incorporated (g/100 g flour). Means followed by the same small letter in the same column did not differ according to Tukey's test ($p < 0.05$). Means followed by the same capital letter in the same line for the same parameter did not differ according to Tukey's test ($p < 0.05$).

low speed. The batter (300 g), at approximately 26 °C, was then transferred to aluminium pans previously greased with butter, and placed in a hearth oven HF 4B (Hypo, Ferraz de Vasconcelos, Brazil) at 160 ± 2 °C for 30 min.

2.2.3. *Technological characteristics of the cakes*

The specific volume was calculated as the ratio of volume to weight. The apparent volume (mL) was measured using the seed displacement methodology according to the AACC method 10-05.01 (AACC, 2010), and the weight (g) determined using a semi-analytical balance PB 3002 (Mettler Toledo, Greifensee, Swiss). The specific volume was determined in triplicates, after an hour of cooling at 24 °C.

The cake crumb colour was evaluated by the tri-stimulus method, followed by the CIE L*C*h colour space, which determined the lightness (L*), chroma (C*) and hue angle (h) values using a Colour Quest II HUNTERLAB (Minolta, Reston, USA) spectrophotometer. The test conditions were as follows: illuminant D65, visual angle of 10° and calibration with reflectance specular included (RSIN). This determination was carried out in triplicate at the centre of the cake by extracting three central slices from each sample.

The cakes were packed into polyethylene plastic bags and stored at room temperature (24 °C) for the shelf life evaluation. The moisture content and firmness values were evaluated after 1, 4 and 7 days of storage. The cake moisture content was determined in triplicate by AACC method 44-15.02 (AACC, 2010), and crumb firmness by AACC method 74-09.01 (AACC, 2010) using a texture analyser (model TA-XT2i; Stable Micro Systems, Surrey, UK) with a 25 kg capacity, and the XTRA Dimension programme equipped with a P/35 mm aluminium cylindrical probe. Two slices of cake were taken from the centre of each cake and the central area of the slices compressed. The cakes were sliced transversely using a FP353 slicer (G.Paniz, Caxias do Sul, Brazil) to obtain uniform 10 mm thick slices. The following parameters were used: pre-test speed of 4.0 mm/s, test speed of 1.0 mm/s, post-test speed of 5.0 mm/s and force of 20 g. Ten measurements were taken per trial.

2.2.4. *Nutritional and sensory characteristics of the cakes*

According to the results obtained in the technological analysis, the cake with the best technological parameters was selected. It had a considerable amount of WCF and presented good specific volume, a slight change in color parameters in relation to the cake without WCF and low firmness values during shelf-life. Both the selected cake and the control cake (without WCF) evaluated for their nutritional and sensory qualities. The optimal chia cake was elaborated with 15 g WCF/100 g flour mixture and 20 g HVF/100 g flour mixture, and the control cake with 0 g WCF/100 g flour mixture and 20 g HVF/100 g flour mixture, as shown in Section 2.2.2.

Proximate analyses was performed according to AACC methods 46-13.01, 30-10.01 and 08-12.01 (AACC, 2010), and the carbohydrate content calculated by difference. The fatty acid profile of the lipids extracted from the cakes was obtained. The central slices were dried according to AACC method 44-15.02 (AACC, 2010), milled and the lipids extracted as described in AOAC method 922.06 (AOAC, 2000). The fatty acid methyl esters (FAMEs) were obtained according to method UNE 55-037-73 (AENOR, 1991) and their compositions determined by capillary gas chromatography (CGC 6890 System Plus, Agilent Technologies, Mississauga, Canada) with a flame ionisation detector (FID). The capillary column was a DB–225 J&W 122-2232 – 50% cyanopropylphenyl-dimethylpolysiloxane one (Agilent Technologies, Mississauga, Canada) with the following dimensions: 30 m long, 0.25 mm inner diameter and 0.25 μm film. The analytical conditions were: injector temperature 220 °C, detector temperature 220 °C; oven temperature 60 °C (1 min) programmed to increase to 210 °C at a rate of 6 °C/min and maintained at this temperature for a further 20 min; carrier gas: N2-UAP; and make-up gas: N2-UAP. The individual FAMEs were identified using the Lipid Standard Sigma 189-1 (Sigma Chemical Co. Ltd., Poole, UK) and Supelco FAME-Mix C4-C24 18919-1 (Supelco Inc., Madrid, Spanish), and the results are expressed as the total fatty acid content (TFA).

Sensory evaluation of the cakes, acceptance tests and the purchasing intention were conducted after 1 day of storage. The samples were evaluated by 40 untrained panellists in isolated booths under white light. The attributes of colour, flavour and texture were evaluated using a 9-point hedonic scale (Stone & Sidel, 1993), where 1 = disliked extremely and 9 = liked extremely, and the purchasing intention on a five point scale, where 1 = “would certainly not buy” and 5 = “would certainly buy”. The samples were served monadically in a random order. Scores from 4 to 5 were considered as a positive purchasing intention.

2.2.5. *Statistical analysis*

Response surface methodology was used to analyse the technological characteristics of the cakes with WCF and HVF as the independent variables, and the specific volume, crumb colour parameters, moisture content and firmness after 1, 4 and 7 days of storage as the dependent variables (responses). The Statistica 5.0 program (Statsoft Inc., Tulsa, USA) was used for the analysis of variance (ANOVA) to obtain the mathematical models and to build the response surfaces ($p < 0.05$). Differences between the average values for moisture content and firmness during the storage period, and the nutritional and sensory results obtained for the cakes were assessed by ANOVA and the Tukey test ($p < 0.05$) using the same statistical programme.

3. Results and discussion

3.1. *Physicochemical characteristics of the raw material*

Table 2 shows the results obtained for the proximate composition of the wheat flour and WCF. When compared to wheat flour, WCF had higher protein, lipid and dietary fibre contents, showing that WCF is an important source of these components. The values obtained for the proximate composition of the WCF were in agreement with the composition reported in the literature, as follows: 9–23 g protein/100 g (Coates & Ayerza, 1996), 25–35 g lipids/100 g (Álvarez-Chávez et al., 2008; Ixtaina et al., 2011; Taga et al., 1984) and 18–41 g fibre/100 g (Ayerza & Coates, 2000; Bushway

Table 2
Composition and particle size range of the wheat flour and whole chia flour.

Components	Wheat flour (g/100 g)	Whole chia flour (g/100 g)
Moisture	11.58 ± 0.01	7.74 ± 0.01
Protein	9.35 ± 0.04	20.01 ± 0.17
Lipids	1.31 ± 0.02	30.97 ± 0.57
Ash	0.70 ± 0.01	4.58 ± 0.13
Carbohydrates	73.60 ± 0.05	5.20 ± 0.83
Total fibre	3.47 ± 0.02	31.51 ± 0.51
Soluble fibre	0.97 ± 0.01	2.96 ± 0.12
Insoluble fibre	2.63 ± 0.01	28.37 ± 0.21

Mesh	Opening (mm)	Retained (g/100 g)	
		Wheat flour	Whole chia flour
20	0.840	0 ± 0	49.69 ± 2.03
32	0.500	0 ± 0	36.47 ± 3.12
60	0.250	4.89 ± 1.41	13.41 ± 2.51
80	0.177	66.12 ± 1.47	0.04 ± 0.02
100	0.149	2.42 ± 0.09	0 ± 0
Bottom	<0.149	26.46 ± 0.93	0 ± 0

Mean ± standard deviation, $n = 3$.

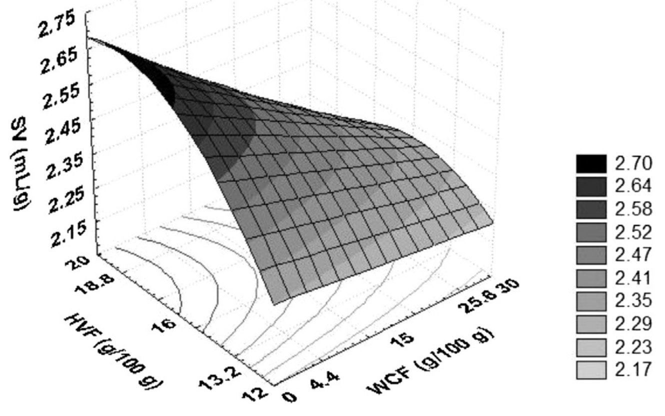


Fig. 1. Response surface for the specific volume (SV) of the cakes prepared with whole chia flour (WCF) and hydrogenated vegetable fat (HVF).

et al., 1981; Reyes-Caudillo et al., 2008). The values obtained for the fibre content showed a wide range of variation, which may have been due to the method used. Chia contains mucilage, which may hinder the complete enzyme digestion. Reyes-Caudillo et al. (2008) reported that the insoluble fraction is the predominant fraction as compared to the soluble fraction.

The WCF showed a greater particle size than the wheat flour (Table 2). In addition, the WCF presented particles with high oil contents, tending to the particle size of flakes. The characteristic of particle size of the raw materials is an important aspect in the preparation of baked products, since the proper particle distribution allows for greater uniformity in the manufactured product (Borges et al., 2006). The particle size has a direct influence on the water adsorption capacity, since smaller flour particles proportionally absorb more water, and can absorb faster than the larger particles (Borges, Ascheri, Ascheri, Nascimento & Freitas, 2003; Linden & Lorient, 1994).

3.2. Technological characteristics

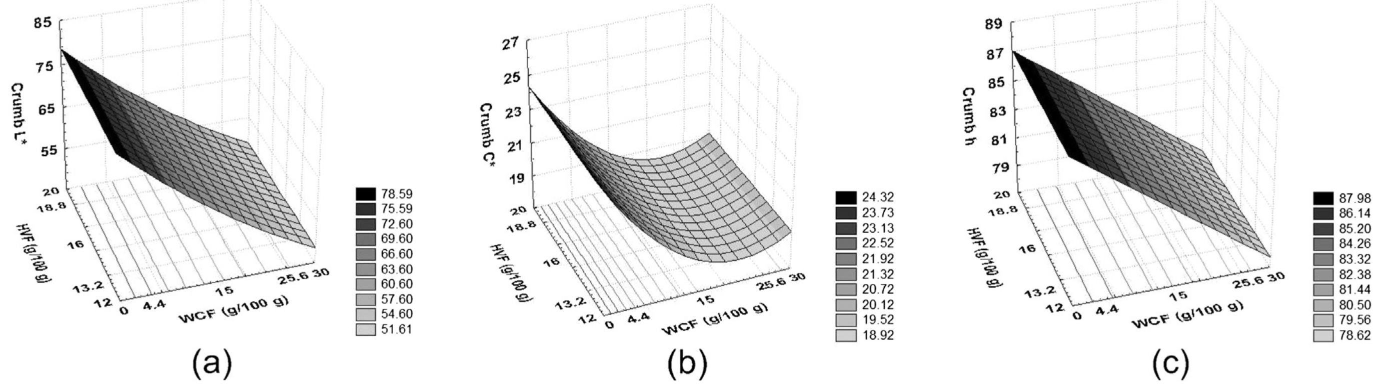
3.2.1. Specific volume

The specific volume of the cakes ranged from 2.15 to 2.67 mL/g and the lowest value corresponded to Assay 7. This cake had the lowest concentration of HVF (12 g/100 g flour mixture) and an intermediate concentration of WCF (15 g/100 g flour mixture). The highest value of specific volume corresponded to Assay 5 with no added WCF (0 g/100 g flour) and an intermediate HVF concentration (16 g/100 g flour mixture).

Equation (1) shows the model for the relationship between WCF and HVF in the interference on the cake specific volume. The response surface (Fig. 1) showed that an increase in WCF concentration from 0 to 30 g/100 g flour mixture contributed to a decrease in specific volume of the cakes. This result is due to the addition of WCF that decreases the amount of gluten present in the formulation. The result also suggests that the incorporation of WCF could interfere in the formation and aggregation of fat around the air bubbles in the batter.

In the traditional fat-sugar creaming method, the air is whipped into the fat as finely distributed bubbles. Once a cream has been formed, part of the flour is beaten in, followed by the egg and milk, forming the batter. The rest of the flour is then added. This allows for the fat/air particles to be finely distributed through the batter. The finer the distribution of the fat and air, the better the final cake volume and crumb structure become (Bennion & Bamford, 1997) and WCF could interfere in this fat/air bubble distribution. Since WCF contains a high level of dietary fibre, it could disturb the air distribution by exerting physical impairment on batter.

From the response surfaces shown in Fig. 1, it can be seen that with lower WCF levels (<15 g/100 g flour mixture), an increase in fat content to levels above 16 g/100 g flour mixture seemed to overcome this effect, since the cakes showed high specific volumes. The increase in viscosity caused by the fat could help overcome the effect of disruption on the fine bubble matrix. This meant that the specific volume remained high with WCF concentrations in the range from 0 to 15 g/100 g flour mixture and HVF concentrations in the range from 16 to 20 g/100 g flour mixture. With higher WCF levels (>15 g/100 g flour mixture), higher HVF levels (>16 g/100 g flour mixture) did not overcome its negative effect on the specific volume, giving values equivalent to those found at low WCF (<15 g/100 g flour mixture) and HVF (<16 g/100 g flour mixture) levels. Possibly the highest WCF concentrations (>15 g/100 g flour mixture) used would require an even greater amount of HVF than those used in the present study, in order to maintain the specific volume, or the addition and/or increase in other ingredients that could help maintain the viscosity of the batter. In order to obtain a minimum specific volume of approximately 2.5 mL/g, it is advisable to work with WCF concentrations up to 15 g/100 g flour mixture and HVF concentrations above 16 g/100 g flour. However, when a nutritional assessment is made, the quantity of added HVF must be evaluated.



(a) (b) (c)

Fig. 2. Response surfaces for the colour parameters of the cakes prepared with whole chia flour (WCF) and hydrogenated vegetable fat (HVF): (a) Crumb L*, (b) Crumb C* and (c) Crumb h.

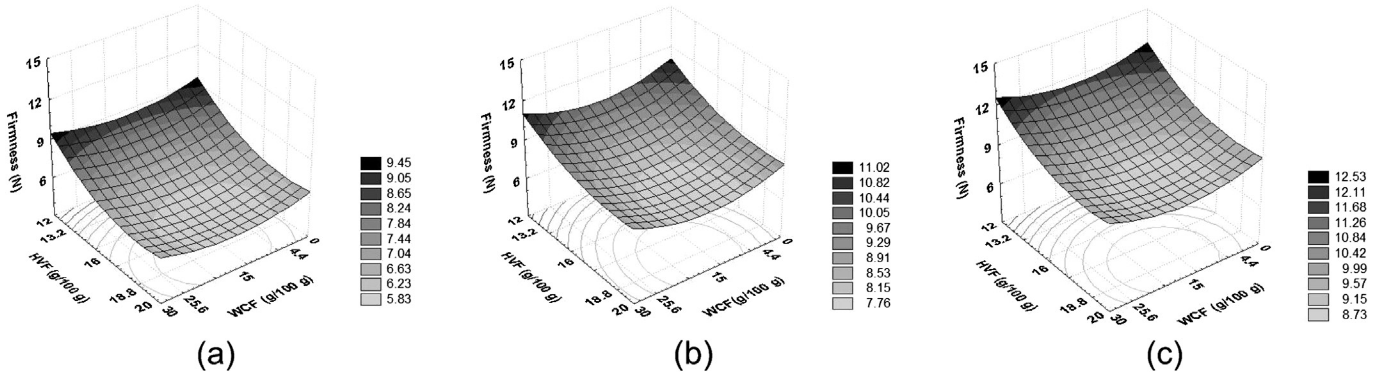


Fig. 3. Response surfaces for the firmness of cakes prepared with whole chia flour (WCF) and hydrogenated vegetable fat (HVF) after (a) 1, (b) 4 and (c) 7 days of storage.

3.2.2. Colour

Colour is one of the most important characteristics in the appearance of a cake, since it contributes to consumer preference in relation to the product. The values for L^*, C^* and h found for the cakes of the experimental design ranged from 48.21 to 77.97, 18.73 to 26.01 and 77.87 to 86.46, respectively. The highest values for these parameters were found in Assay 5, which had no added WCF. As expected, due to its own colour, the WCF had an effect on all the colour parameters evaluated, as can be seen in Equations 2, 3 and 4. WCF contributed to a decrease in these values, making the crumb colour darker (lower L^*), with a less saturated colour (lower C^*), and tending more to red (lower h) (Fig. 2). The addition of 15 g WCF/100 g flour mixture (Assays 7–11) decreased the values of L^*, C^* and h approximately by 22, 26 and 5% respectively, compared to cake with no WCF addition (Assay 5). The colour parameters were not influenced by HVF, which is similar to results obtained by Capriles and Areas (2005).

3.2.3. Moisture

The addition of WCF and HVF had no significant effect on the moisture content after 1, 4 and 7 days of storage (Table 1), and it was not possible to establish mathematical models for these responses as a function of the ingredients used. No linear, quadratic or interaction effect was significant ($p < 0.05$), indicating that WCF and HVF did not interfere with moisture content of cakes. On storage days 1, 4 and 7, the moisture values ranged from 23.46 g to 24.72 g/100 g, 23.64 g–25.01 g/100 g, and 22.36 g/100 g–24.15 g/100 g, respectively.

The values obtained for the moisture content throughout the storage period showed very little change. None of the formulations showed any loss of moisture on day 4 of storage, and only a little on day 7. Thus, the cakes presented good water retention capacity during their shelf-life. This probably occurred due to the fact that the fat acts as a moisture barrier when used in a recipe. The quality of bakery foods is affected by moisture. With no fat to prevent moisture uptake, a baked product may pick up moisture and become soggy or lose moisture and dry out (Bennion & Bamford, 1997). Moreover, WCF contains high levels of dietary fibre (Table 2), which helps to maintain the moisture of the product. Polysaccharides, such as dietary fibres, are hydrophilic molecules, with numerous free hydroxyl-groups which can form hydrogen bonds with water. Consequently, soluble and insoluble polysaccharides have the ability to hold water (Oakenfull, 2001). Furthermore, possible interactions between the fibre and starch could occur, and this could delay starch retrogradation (Gómez, Ronda, Blanco, Caballero & Apesteguía, 2003) avoiding the loss of moisture during storage.

3.2.4. Firmness

Table 1 shows the values for cake firmness on storage days 1, 4 and 7. Equations 5, 6 and 7 present the relationships between WCF and HVF for this parameter on storage days 1, 4 and 7. The three response surfaces obtained from the models were very

Table 3
Nutritional and sensory characterization of the standard cake and optimal chia cake.

	Standard cake	Optimal chia cake
Centesimal composition (g/100 g)		
Moisture	24.64 ± 0.21 a	24.69 ± 0.69 a
Protein	7.98 ± 0.04 b	8.55 ± 0.10 a
Lipids	12.44 ± 0.15 b	16.28 ± 0.25 a
Ash	1.18 ± 0.02 b	1.40 ± 0.02 a
Carbohydrates	53.76 ± 0.26 a	49.08 ± 0.74 b
Fatty acid profile (g/100 g)		
C 6:0	0.12 ± 0.05 a	0.15 ± 0.02 a
C 8:0	0.48 ± 0.18 a	0.28 ± 0.07 a
C 10:0	0.33 ± 0.07 a	0.26 ± 0.01 a
C 12:0	1.74 ± 0.23 a	1.31 ± 0.05 b
C 14:0	2.01 ± 0.19 a	1.78 ± 0.05 a
C 15:0	0.19 ± 0.06 a	0.13 ± 0.01 a
C 16:0	24.98 ± 0.21 a	23.11 ± 0.37 b
C 17:0	0.07 ± 0.02 a	0.16 ± 0.01 a
C 18:0	9.99 ± 0.29 b	10.76 ± 0.08 a
C 20:0	0.28 ± 0.08 a	0.33 ± 0.05 a
C 22:0	0.14 ± 0.05 a	0.19 ± 0.01 a
Total SFA	40.33 ± 0.42 a	38.45 ± 0.69 b
C 14:1	0.04 ± 0.01 a	0.08 ± 0.01 a
C 16:1	0.58 ± 0.16 a	0.54 ± 0.05 a
C 18:1	42.22 ± 0.85 a	38.49 ± 0.15 b
C 20:1	0.24 ± 0.08 a	0.13 ± 0.06 a
Total MUFA	43.09 ± 0.80 a	39.24 ± 0.34 b
C 18:2 $\omega -6$	16.37 ± 0.38 a	15.30 ± 0.12 b
C 18:3 $\omega -3$	0.21 ± 0.01 b	7.01 ± 0.24 a
Total PUFA	16.58 ± 0.38 b	22.31 ± 0.35 a
SFA:MUFA:PUFA ratio	1:1.07:0.41	1:1.02:0.58
PUFA/SFA	0.41 ± 0.01 b	0.58 ± 0.02 a
$\omega -6/\omega -3$	77.11 ± 1.93 a	2.18 ± 0.06 b
Sensory acceptance[a]		
Colour	7.9 ± 0.9 a	6.6 ± 1.8 b
Taste	7.6 ± 1.1 a	6.8 ± 1.8 b
Texture	7.6 ± 1.1 a	7.2 ± 1.4 a
Purchase intention[b]	4.1 ± 0.9 a	3.8 ± 1.0 a
Positive purchase intention (%)[c]	77	60

Mean ± standard deviation. Proximate composition and fatty acid profile ($n = 3$); sensory evaluation ($n = 40$). Means followed by the same letter in the same line did not differ according to Tukey's test ($p < 0.05$). SFA = saturated fatty acids, MUFA = mono unsaturated fatty acids, PUFA = polyunsaturated fatty acids.

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

[b] Hedonic scale ranging from 1 = "would certainly not buy" to 5 = "would certainly buy".

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

similar, with displacement almost only along the *Z* axis (showing an increase in firmness during storage) (Fig. 3). Moreover, a greater effect of HVF on firmness can be observed in relation to WCF and an increase in HVF resulted in a decrease in firmness. The addition of intermediate concentrations of WCF (close to 15 g/100 g flour mixture) and the highest concentrations of HVF (>16 g/100 g flour mixture) resulted in less firm cakes. However, the addition of intermediate concentrations of WCF (close to 15 g/100 g flour mixture) and the lowest concentrations of HVF (close to 12 g/100 g flour mixture) resulted in very firm cakes. This can be explained by the reduction in HVF, which resulted in a lower aeration capacity, worse crumb structure and, consequently, greater firmness. Lakshminarayan et al. (2006) also found that with a gradual reduction in the fat content of the cakes, they became less soft, requiring more force to compress them. This fact could also be a reflection of the lower specific volume observed in these WCF and HVF concentration ranges. According to Faridi (1985), the volume has an influence on crumb firmness, since for volumes obtained from equivalent weights, the differences in volume usually resulted in differences in wall thickness and gas cell size.

A decrease in firmness is expected with an increase in the amount of WCF, since the WCF contributed to a decrease in the starch concentration of the cakes. It is believed that starch is one of the components responsible for the staling of bakery products, due the retrogradation process and its interaction with proteins (Lai & Lin, 2006). Moreover, with an increase in the amount of WCF there was an increase in the fibre and lipid concentrations of the cake. However this was only observed for an increase in WCF concentration from 0 to 4.4 g/100 g flour mixture, and for the same HVF concentration, an increase in WCF from 4.4 g to approximately 25.6 g/100 g flour mixture showed no change in firmness. However, an increase in WCF from 25.5 to 30 g/100 g flour mixture resulted in an increase in firmness, possibly due to the interference of WCF on the alveoli structure (coarse crumb structure). The structure of a cake consists of air cells distributed throughout a food matrix, and the ingredients influence the size and distribution of the air cells within the cake structure (Sozer et al., 2011), which can affect the texture.

According to the results shown in Table 1, a gradual increase in firmness of the cake crumb can be seen with the increase in storage time. Firming of the crumb during storage is a common phenomenon (Ji, Zhu, Zhou & Qian, 2010). On storage days 1, 4 and 7 the firmness values ranged from 5.34 to 8.89, 7.05 to 10.29 and 7.82–12.56 N, respectively. Assays 1 and 6 showed an increase in firmness on storage day 7, despite the fact that these assays presented no significant moisture loss during storage.

3.3. *Nutritional and sensory characteristics*

The incorporation of WCF into the cake formulation improved the nutritional value of the product (Table 3). The optimal chia cake (containing 15 g WCF/100 g flour mixture and 20 g HVF/100 g flour mixture) presented a significant increase in the protein (7 g/100 g), lipids (31 g/100 g) and ash (19 g/100 g) contents as compared to the control cake (0 g WCF/100 g flour mixture and 20 g HVF/100 g flour mixture). This increase may be due to the high contents of these nutrients in the WCF (Table 2) as discussed previously.

With respect to the lipids, it is important to emphasize the improvement in the fatty acid profile of the optimal chia cake formulation (Table 3), which presented a decrease in saturated total fatty acids (5%) and mono saturated acids (9%) and an increase in polyunsaturated fatty acids (35%). The increase in polyunsaturated fatty acids was mainly due to the increase in the α-linolenic acid content (3238%), which made the optimal chia cake a source of ω-3 fatty acids. Furthermore, an excellent omega-6/omega-3 ratio was observed in the optimal chia cake formulation (2.18/1), which was not found in the control cake.

The cake produced with the addition of WCF showed good sensory acceptance. Although it presented lower scores than the control cake for the attributes of colour and flavour, the scores for texture were similar for both samples. In general, the cakes were well accepted by the consumers, with scores between 6 and 8 (“liked slightly” to “liked a lot”) for the sensory attributes studied. The results for purchasing intention varied between “maybe buy, maybe not buy” and “would certainly buy” for the product, showing no statistical difference between the formulations. About 60% of the panellists would possibly or certainly buy the cake, representing a positive purchasing intention.

4. Conclusions

This study showed that the incorporation of whole chia flour (WCF) resulted in a nutritionally enhanced pound cake, mainly in relation to the omega-3 α-linolenic acid content and omega-6/omega-3 ratio. It is possible to incorporate WCF into pound cake formulations and obtain a product with good technological and sensory performances. The presence of hydrogenated vegetable fat (HVF) helps to minimize the adverse effects of WCF on the specific volume and firmness of the cakes. The best technological results were obtained for cakes produced with up to 15 g WCF/100 g flour mixture and from 16 to 20 g HVF/100 g flour mixture.

Appendix A

$$\begin{aligned}\text{Specific volume } &= 2.47 - 0.12\ \text{WCF} - 0.05\ \text{HVF} - 0.07\ \text{HVF}^2 \\ &\quad - 0.06\ \text{WCF HVF}\left(r^2 = 0.8351;\ \text{Fcal/Ftab} = 1.55\right)\end{aligned} \tag{1}$$

$$\begin{aligned}\text{Crumb L}^* &= 61.37 - 10.63\ \text{WCF} + 1.12\ \text{WCF}^2 \\ &\quad \times \left(r^2 = 0.9957;\ \text{Fcal/Ftab} = 208.68\right)\end{aligned} \tag{2}$$

$$\begin{aligned}\text{Crumb C}^* &= 18.89 - 1.82\ \text{WCF} + 1.44\ \text{WCF}^2 \\ &\quad \times \left(r^2 = 0.8173;\ \text{Fcal/Ftab} = 4.00\right)\end{aligned} \tag{3}$$

$$\text{Crumb h} = 82.38 - 3.33\ \text{WCF}\left(r^2 = 0.9832;\ \text{Fcal/Ftab} = 102.88\right) \tag{4}$$

$$\begin{aligned}\text{Firmness on day 1 of storage } &= 5.86 + 0.44\ \text{WCF}^2 \\ &\quad - 0.98\ \text{HVF} + 0.55\ \text{HVF}^2 \\ &\quad \times \left(r^2 = 0.8660;\ \text{Fcal/Ftab} = 3.47\right)\end{aligned} \tag{5}$$

$$\begin{aligned}\text{Firmness on day 4 of storage } &= 7.77 + 0.63\ \text{WCF}^2 - \\ &\quad 0.81\ \text{HVF} + 0.43\ \text{HVF}^2 \\ &\quad \times \left(r^2 = 0.7807;\ \text{Fcal/Ftab} = 1.91\right)\end{aligned} \tag{6}$$

$$\begin{aligned}\text{Firmness on day 7 of storage } &= 8.75 + 0.56\ \text{WCF}^2 \\ &\quad - 1.04\ \text{HVF} + 0.60\ \text{HVF}^2 \\ &\quad \times \left(r^2 = 0.7242;\ \text{Fcal/Ftab} = 1.41\right)\end{aligned} \tag{7}$$

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