LWT - Food Science and Technology 95 (2018) 85–91

Contents lists available at ScienceDirect

LWT - Food Science and Technology

journal homepage: www.elsevier.com/locate/lwt

Partial replacement of wheat flour by pecan nut expeller meal on bakery products. Effect on muffins quality

L. Marchetti*, A.N. Califano, S.C. Andrés

Centro de Investigación y Desarrollo en Criotecnología de Alimentos (CIDCA), CONICET, CICPBA, Facultad de Ciencias Exactas, UNLP. 47 y 116, La Plata, 1900, Argentina

ARTICLE INFO

Keywords:
By-product
Press-cake
Image analysis
Sensorial analysis
Texture

ABSTRACT

The objective of the present work was to evaluate the effect of replacing up to 40 g/100 g wheat flour by pecan nut expeller meal on baking quality of a typical muffin formulation. Baked samples were subjected to several assays: yield, height of the specimen, color, crumb moisture, texture (TPA), microstructure by image analysis. Replacement of 30 g/100 g of wheat flour by expeller significantly height of the product. Also hardness was greatly reduced (52.4%) when 30 g/100 g of PEM was included. The addition of PEM lead to a darker crumb, the browning index was 38% higher when 40 g/100 g of wheat flour was replaced by expeller. Muffins showed a very good sensorial acceptance, scoring 7.9 into a 9-point hedonic scale. Thus a by-product from pecan oil industry was successfully employed in muffins, adding value, and broadening its potential applications in other bakery products, resulting in economic benefits.

1. Introduction

Nut consumption had been associated with less cardiovascular mortality index (Haddad, Jambazian, Karunia, Tanzman, & Sabaté, 2006; Yang, Liu, & Halim, 2009) due to their healthier lipid profile. Pecan nut (*Carya illinoinensis*) belongs to *Juglandaceae* family and is native of south of United States and north of Mexico (Hancock, 1997). At XX century beginnings, its farming was extended to several countries including Australia, South Africa, Israel, Brazil, and Argentina (Pinheiro do Prado, Monalise Aragão, Fett, & Block, 2009). Nuts are source of unsaturated fatty acids, proteins, fiber, and micronutrients (Yang et al., 2009). Main fatty acids in pecan nuts are oleic and linoleic acid, contributing 56.4% and 18.9% of total lipid, respectively. In addition, pecan nuts are rich in fiber, containing 10–11 g/100 g of dietary fiber. Also, pecans are a rich source of γ- and a poor source of α-tocopherol, containing 24.4 and 1.4 mg/100 g of nut, respectively, and contains complex flavonoid substances, especially proanthocyanidins, or condensed tannins, substances that are recognized for their effective inhibition of lipid oxidation in foods and possibly in biological systems (Haddad et al., 2006; Kornsteiner, Wagner, & Elmadfa, 2006; Pinheiro do Prado et al., 2009). Numerous epidemiological investigations have established an association between diets rich in phytochemicals and reduced risk of suffering from many civilization-related diseases (Mildner-Szkudlarz, Siger, Szwengiel, & Bajerska, 2015).

Pecan nut expeller cake or meal is a by-product from pecan oil industries that gives good-quality oil, and a press cake residue. Despite its high oil content, nutritional value and pleasant sensory characteristics, the expeller is normally employed as animal feed, a low-value by-product. Nevertheless it seems to be a promising product which can be further used as food ingredient for bakery products and for many frequently consumed foods (Salvador, Podestá, Block, & Ferreira, 2016).

Baked products are suitable for functional food. They are widely consumed, can be manufactured and frozen. Afterwards, they must be thawed, and require little preparation to be consumed (Aliani, Ryland, & Pierce, 2011).

To increase dietary fiber in baked goods products from different sources, mango or potato peels, apple, orange or grape pomace can be incorporated into recipes for partially replacing flour, sugar or fat (Ajila, Leelavathi, & Rao, 2008; Arora & Camire, 1994; Masoodi, Sharma, & Chauhan, 2002; Mildner-Szkudlarz et al., 2015; O'Shea, Doran, Auty, Arendt, & Gallagher, 2013; Sudha, Baskaran, & Leelavathi, 2007).

Dietary fiber incorporation in sweet baked goods is associated with higher batter viscosity related to fiber's physicochemical properties such as high water binding capacity (Gularte, de la Hera, Gómez, & Rosell, 2012). This property reduces water availability for other ingredients and, consequently, affects product characteristics such as crumb hardness and chewiness, or volume (Grigelmo-Miguel, Carreras-Boladeras, & Martín-Belloso, 1999; Lebesi & Tzia, 2011; Martínez-Cervera, Salvador, Muguerza, Moulay, & Fiszman, 2011; Struck,

---

* Corresponding author.

E-mail address: marchetti.lucas@quimica.unlp.edu.ar (L. Marchetti).

https://doi.org/10.1016/j.lwt.2018.04.050
Received 22 June 2017; Received in revised form 16 April 2018; Accepted 17 April 2018

Gundel, Zahn, & Rohm, 2016; Sudha et al., 2007).

It has been stated that nuts addition could improve bread and bakery products nutritional quality. Moreover, nuts have beneficial effects on health, above all on chronic non-communicable diseases, so they are regarded as natural functional foods (Gómez, Oliete, Caballero, Ronda, & Blanco, 2008). Pecan nut expeller meal (PEM) incorporated into baked products as muffins in replacement of wheat flour could improve its lipid profile and fiber content, also it would increase mineral content (manganese, potassium, calcium, iron, magnesium, zinc, selenium). Thus PEM utilization in baked products would result into a healthier alternative and would add value to underused by-product. However, physicochemical (texture, volume) and sensorial characteristics should be studied, when wheat flour is replaced in bakery products (Damodaran, 2008, pp. 217–329). Thus the objective of this work was to study the effect of wheat flour partial replacement with pecan nut expeller meal (PEM) in muffins quality.

2. Materials and methods

2.1. Components

All formulations were made with same common components: all-purpose wheat flour (WF) (Molino Campodónico, La Plata, Argentina), white granulated sugar (Ledesma, Tucumán, Argentina), whole dried egg (Ovobrand, Brandsen, Argentina), dried milk (La Serenísima, General Rodríguez, Argentina), refined sunflower oil (Molino Cañuelas, Cañuelas, Argentina), vanilla essence (Saporiti, Buenos Aires, Argentina) sodium chloride (Anedra, San Fernando Argentina), sodium bicarbonate (Biopack Buenos Aires, Argentina), and tartaric acid (Biopack Buenos Aires, Argentina). WF composition was: protein 13.26 ± 0.03 g/100 g (Kjeldahl factor = 5.7), moisture 13.04 ± 0.03 g/100 g, lipids 1.2 ± 0.1 g/100 g and ashes 0.68 ± 0.04 g/100 g, wet gluten 25.10 ± 0.14, dry gluten 9.01 ± 0.11 (g gluten/100 g flour) (Corral, Cerrutti, Vázquez, & Califano, 2017).

Pecan nut expeller meal (PEM) was provided by Nucana (Entre Ríos, Argentina). It was obtained from recently harvested pecan nuts. PEM was processed immediately after its reception to obtain a homogeneous sample using a commercial food processor (Universo, Rowenta, Germany, 14 cm blade), sieved to pass through a 350 μm mesh in order to obtain an homogenous coarse-like powder and stored at 10 °C in vacuum bags to avoid deterioration. PEM composition (lipids 51.4 ± 0.1 g/100 g, dietary fiber 13.6 ± 0.1 g/100 g, proteins 13.2 ± 0.01 g/100 g, carbohydrates 11.96 ± 0.07 g/100 g, moisture 5.66 ± 0.03 g/100 g, and ashes 3.67 ± 0.05 g/100 g) as well as its fatty acid (FA) profile (saturated FA 6.09%, monounsaturated FA 63.27%, and polyunsaturated FA 29.93%) were determined in a previous work (Marchetti, Romero, Andrés, & Califano, 2017).

2.2. Wheat flour and expeller functional properties

Water and oil absorption capacities (WAC and OAC, respectively) were determined by weighting 1 g of wheat flour or pecan nut expeller and vortexed with 10 mL of distilled water or oil at highest speed for 2 min (Beuchat, 1977; Chakraborty, 1986). Mixtures were allowed to stand at room temperature (25 °C) for 30 min, and then centrifuged at 3000 × g for 20 min. Supernatants were decanted and centrifuge tubes containing sediments were weighed. Results were expressed as mL H_2O or oil/g of flour or expeller for WAC and OAC, respectively. Four replicates were done for each component.

2.3. Product manufacture

A reference muffin recipe was employed as control (C) 100 g of control dough contained the following components: 36.53 g wheat flour, 26.94 g water, 11.42 g sunflower oil, 18.26 g white sugar, 2.283 g skim milk powder, 2.283 g whole egg powder, 0.457 g sodium chloride, 0.685 g tartaric acid, 0.685 g sodium bicarbonate, and 0.455 g vanilla essence. Muffins containing pecan nut expeller were prepared by replacing 10, 20, 30, and 40% of wheat flour with PEM. Thus samples were coded as: C (control formulation without PEM), P10-40 (formulations with 10, 20, 30, and 40% of wheat flour replaced with PEM).

For all muffins manufacture the same procedure was followed: egg and milk powders were first mixed with water and vanilla essence and let to rest for 10 min for hydration. Afterwards, sunflower oil was incorporated and emulsified with a hand held homogenizer (Braun Mq 300, Braun, Buenos Aires, Argentina) for 1 min at 1100 rpm. Meanwhile wheat flour (control muffin, C) or milled pecan nut expeller and wheat flour (pecan nut muffins, P), salts, and white sugar were blended. Then, liquid and solid ingredients were gently combined and mixed with a commercial food processor (Universo, Rowenta, Erbach, Germany) for 1 min, at 150 rpm until homogeneity.

Portions of 80 ± 0.1 g batter were filled in paper cups placed in metallic muffins pans. Muffins were baked in groups of 12 units in a pre-heated convective oven (Ariston FM87-FC, Ariston, Fabriano, Italy) at 140 °C for 37 min, and cooled at room temperature. Determinations were made over muffins kept 36 h in hermetic plastic boxes preserved from moisture loss.

2.4. Product characterization

2.4.1. Process yield

Process yield was determined by weighting raw batter and baked product, and expressed as g/100 g of initial sample weight (6 replicates per batch, 2 batches per formulation were measured).

2.4.2. Product height

Height of cooked products removed from their paper cups was measured from base to the highest top using an electronic digital caliper (Schwyz, Schwyz, Switzerland) (6 replicates per batch, 2 batches per formulation were measured).

2.4.3. Crumb moisture

Crumb from muffin center was obtained and its moisture determined in an oven at 105 °C until constant weight (3 replicates per batch, 2 batches per formulation were measured).

2.4.4. Crumb and crust color

Color determinations were performed using a Chroma Meter CR-400 colorimeter (Minolta Co., Ramsey, New Jersey, USA) on surface of transversally cut muffin slices for crumb color and directly on crust for crust color. CIE-LAB parameters (lightness, L; redness, $a^* > 0$ or greenness, $a^* < 0$, and yellowness, $b^* > 0$ or blueness $b^* < 0$) were determined (9 replicates per batch, 2 batches per formulation were measured). The aperture size was 8 mm and a *C, D65 illuminant was employed. Once color parameters were acquired browning index (BI) was calculated as:

$$BI = \frac{[100\,(x - 0.31)]}{0.172} \tag{1}$$

where

$$x = \frac{(a^* + 1.75L^*)}{(5.645L^* + a^* - 3.012b^*)} \tag{2}$$

BI represents brown color purity when non-enzymatic browning takes place. Although this index was originally developed to represent browning of liquid model systems, recently, it has been satisfactorily used to report browning variation of several bakery products (Ureta, Olivera, & Salvadori, 2014; Yang et al., 2014).

2.4.5. Crumb texture

Texture Profile Analysis (TPA) was performed on muffins (Bourne, 1978; Brennan & Bourne, 1994) at a controlled room temperature (25 °C). Samples (25.6 mm thick and 28.8 mm diameter) were cut from muffin center and compressed twice to 30% of their original height between flat plates using a TAXT2i Texture Analyzer (Stable Micro Systems, Godalming, UK) interfaced with a computer, using the software supplied by Texture Technologies Corp. In these experiments the probe diameter was 75 mm, and was operated at 0.5 mm/s. Hardness (peak force of first compression cycle, N), cohesiveness (ratio of positive areas of second cycle to area of first cycle, J/J, dimensionless), adhesiveness (negative force area of the first bite represented the work necessary to pull the compressing plunger away from the sample, J), chewiness (hardness x cohesiveness x springiness, N), springiness (distance of the detected height of the product on the second compression divided by the original compression distance, mm/mm, dimensionless) and resilience (area during the withdrawal of the first compression divided by the area of the first compression, J/J, dimensionless) were determined (6 replicates per batch, 2 batches per formulation were measured).

2.4.6. *Crumb structure characterization*

Digital image analysis was used to characterize crumb structure. (6 replicates per batch, 2 batches per formulation were analyzed). Slices were horizontally cut from muffin center and crumb images were captured using a flat-bed scanner (HP 4500 Hewlett Packard, Palo Alto, CA, USA). Obtained images (600 DPI) were analyzed using Image J 1.48q software (National Institutes of Health, Stapleton, NY, USA, available at http://rsb.info.nih.gov/ij/) that uses contrast between two phases (pores and solids parts) in the image. Scanned color images were first converted to gray scale and binarized to obtain pore area fraction as total pore area/total area of the slice (cm^2/cm^2), diameter of pores, and pore density (number of pores/cm^2). Diameter limits of 0.1 and 6 mm were established.

Pore volume was calculated as:

$$V = \frac{\pi D^3}{6} \tag{3}$$

where

D is the diameter of the pore (mm).

Pore size distributions were analyzed as histograms with pore volume fractions (V pore within diameter range/Total pore volume) divided in 11 diameter ranges.

D [4,3], equivalent volume mean (De Brouckere diameter, mm), reflects the size of pores majority of the gas volume. It is most sensitive to the presence of large pores in the size distribution and is identical to the weight equivalent mean if density is constant. It was calculated as:

$$D[4,3] = \frac{\sum_i^N n_i D_i^4}{\sum_i^N n_i D_i^3} \tag{4}$$

where

D_i is the diameter of the *ith* pore (mm).

n_i is the number of pore with D_i diameter (mm).

Pore specific perimeter was calculated as the sum of all pores perimeters divided the total area of the slice.

2.4.7. *Sensorial evaluation*

Control muffin (C) and two pecan nut muffin formulations with the best physicochemical characteristics were tested by forty-eight panelists. They were trained and semi-trained personnel (faculty members, research fellows and postgraduate students) members of CIDCA, aged between 25 and 56 years.

Samples were served in plastic trays in a randomized and balanced manner. Tap water was provided for palate cleansing between samples. Acceptance testing was conducted using a 9-point hedonic scale (9 = like extremely, 1 = dislike extremely) to assess the following attributes: appearance, color, firmness, crumb moisture, taste, and overall acceptance. Also to obtain further information, color, firmness, and crumb moisture were evaluated using a just-about-right (JAR) scale of 5 points, with −2 = extremely less than the ideal; 0 = ideal, and 2 = extremely over the ideal. Also panelists were asked to inform which their preferred formulation was.

In addition, a penalty analysis or mean drop analysis was performed since it includes easily interpretable data that link specific product attributes in need of adjustment with the impact their being not "just right." Penalty analysis also separates attributes into those that appear to have impacted Overall Liking from those that have generated "complaints," those attributes that consumers say are not just right, but whose current level has in reality, not impacted liking and it was obtained as (Rothman & Parker, 2009):

$$Penalty = (OL_{NJ} - OL_J) \tag{5}$$

where,

OL_{NJ} = mean of the overall liking of the panelists of one of each non-JAR subgroup.

OL_J = mean of the overall liking of the panelists of the JAR subgroup.

The penalty is calculated when the percentage of non-JAR responses exceeded 20% to eliminate smaller, less impactful attributes from considerations.

2.5. *Statistical analysis*

Analyses of variance (ANOVA) were conducted separately on dependent variables studied considering each formulation as a level in a one-way factorial design. For simultaneous pairwise comparisons, least significance differences (LSD) test was chosen. Differences in means and F-tests were considered significant when $P < 0.05$. All statistical procedures were computed using SYSTAT software (SYSTAT, Inc., Evanston, IL). Experimental data were reported as mean values, standard error of the mean (SEM) is informed between parenthesis.

For JAR tests, chi square, and paired *t*-test for binary data were performed in order to obtain further information.

3. Results and discussion

3.1. *Physical characteristics*

Process yield is a parameter related to industrial interest since more yield leads to more product weight. Also during baking process, water is the principal released component that leads to weight loss. So this parameter could be related to matrix -water interactions. Replacement of wheat flour with 20% or 30% PEM resulted in higher process yields (Table 1, formulations P20 and P30). This improvement could be attributed to PEM's higher water and oil absorption capacities ($WAC_{PEM} = 1.83 \pm 0.06$ g H_2O/g, $OAC_{PEM} = 2.61 \pm 0.09$ g oil/g) with respect to wheat flour ($WAC_{WF} = 1.57 \pm 0.05$ g H_2O/g, and $OAC_{WF} = 1.83 \pm 0.08$ g oil/g), and probably related to the high PEM fiber content (13.6 ± 0.1 g/100 g, Marchetti et al., 2017). Nevertheless P40 had a lower yield, implying than more water was released. An explanation to this dual behavior could be related with the highest specific pore perimeter exhibited by P40 (Table 1). In this case, the system could interchange water vapor more easily with the atmosphere because more contact area was formed. Lowering process yield of the sample. Table 1 also shows that P30 crumb moisture was higher ($P < 0.05$) than C, in accordance with the above mentioned results. Other samples did not show significant differences among them.

Moreover, muffins with significantly larger height were obtained using P20 or P30 formulations (Table 1). Digital image analysis (Fig. 1) revealed significant differences in terms of crumb structure between muffins at various addition levels ($P < 0.05$). Moreover, histograms

Table 1
Characteristics and structural properties of muffins.

Code	Process Yield** (g/100 g)	Crumb moisture*** (g H_2O/100 g)	Height** (mm)	D [4,3]** (mm)	Pore density** (pores/cm^2)	Pore specific perimeter** (mm/cm^2)	Pore area fraction** (cm^2/cm^2)
C	85.5^c (0.5)	25.4^b (0.7)	47.5^c (0.4)	2.26^c (0.09)	5.96c (0.14)	45^d (2.4)	0.097^d (0.003)
P10	86.3^c (0.4)	26.7^{ab} (0.3)	48.7^{bc} (0.3)	2.48^b (0.05)	6.41c (0.08)	52^c (0.8)	0.106^d (0.005)
P20	87.7^b (0.3)	27.1^{ab} (0.2)	50.2^a (0.3)	2.64^b (0.05)	6.54c (0.12)	49^c (2.4)	0.169^b (0.008)
P30	88.7^a (0.4)	28.0^a (0.5)	49.0^{ab} (0.3)	2.92^a (0.06)	8.37b (0.02)	64^b (3.2)	0.190^a (0.007)
P40	85.5^c (0.3)	27.4^{ab} (0.5)	47.9^{bc} (0.3)	2.54^b (0.4)	9.74a (0.13)	88^a (4.1)	0.136^c (0.002)

* Different letters in the same column indicate significant differences ($P < 0.05$).
** 2 Batches, 6 replicates each.
*** 2 Batches, 2 replicates each.
Codes: control formulation (C), formulation with 10, 20, 30, and 40% wheat flour replaced with pecan nut expeller (P10, P20, P30, P40, respectively).

(Fig. 1) clearly showed that PEM presence increased average pore size according to D [4,3] (Table 1). Although higher PEM proportion lead to higher pore density, P20 and P30 formulations exhibited more height that indicated more gas retention in the products. Thus height does not just depend on the number of pores, but on pore size distribution. (Table 1, Fig. 1). These formulations (P20 and P30) also exhibited the highest pore area fraction which is proportional to total gas volume in the crumb. It can be seen that the above mentioned formulations showed the highest area fraction indicating a more sponge-like structure. When PEM was added, lipids could have a plasticizing effect on the matrix and fiber could improve gas retention and water holding capacity. Demirkesen, Sumnu, and Sahin (2013) found a similar trend when tiger nut flour was used in replacement of rice flour in gluten free formulations. When 40% of PEM was added the consequent reduction in gluten proteins would negatively impact on gas retention and in this case PEM would be acting as bulk load, weakening the gluten matrix, leading to less gas retention.

PEM incorporation in batters led to baked products with higher height. This could be attributed to improved air retention. Considering the important fiber amount in PEM, an explanation of this effect can be proposed. Nasar-Abbas and Jayasena (2012) observed a correlation between fiber content and wheat flour-based batters consistency; batter consistency is important since it is related to the capacity of retaining air. If consistency is too low, cake volumes are small because of batter poor effectiveness to entrap air (Lakshminarayan, Solid, Collins, Anderson, & Herzog, 2006). In the present work http://www.sciencedirect.com/science/article/pii/S0023643809001960?np=y-bib17, as fiber content increased so did batter consistency, thus resulting in higher heights; however at higher fiber content, excessive consistency could also diminish muffin quality since it could impede batter expanding as can be seen in formulation P40 where all quality indicators are diminished.

3.2. Color and textural parameters

Crust lightness (L*) and yellowness (b*) diminished as wheat flour (WF) was substituted with PEM, while redness (a*) showed an increment (Table 2). Nevertheless, BI, which reflects crust brown color, remained unchanged with PEM addition, resulting in an average value of 38 ± 4, probably because the error in each of the three parameters produces a larger error en the determination of BI, thus resulting in a non-significant effect ($P > 0.05$).

Regarding crumb color, it strongly depends on raw components since temperature is not high enough to give an extensive Maillard or caramelization reactions. It was observed that when PEM percentage was increased, L* and b* value decreased while a* increased (Table 2), as observed in crust color. However, PEM addition significantly ($P < 0.05$) affected crumb BI value, which presented a trend to brownish (> BI) as PEM increased. This result is easily understood considering the differences in color parameters of PEM ($L^* = 44.5 \pm 0.6$, $a^* = 11.5 \pm 0.4$, $b^* = 24.8 \pm 0.4$, $BI = 96.5 \pm 2.3$) and WF ($L^* = 88.4 \pm 0.4$, $a^* = 1.27 \pm 0.01$, $b^* = 2.42 \pm 0.02$, $BI = 3.62 \pm 0.3$). Thus the resulting crumb color is related to the relative proportion of PEM/WF in the system.

Other authors reported similar results for muffins enriched with different fiber sources (Manuel Gómez, Moraleja, Oliete, Ruiz, & Caballero, 2010) or lupin flour (Nasar-Abbas & Jayasena, 2012).

Pecan nut expeller addition to the formulation to partially replace WF had a significant effect on texture parameters (Table 3). With an increase in PEM up to 30% (P30) hardness decreased significantly ($P < 0.05$). Chewiness, a parameter positively correlated with how easy a food can be broken down in mouth, followed the same trend as hardness. Cohesiveness increased beyond 20% PEM addition (P20 formulation). These results could be related with the higher lipid content in PEM muffins than control ones (C), as a consequence of wheat flour replacement with PEM; the net result was a softer and more cohesive product. Paraskevopoulou and Kiosseoglou (1997) observed a reduction in cohesiveness in cakes when lipid extracted-yolk was employed. These authors suggested that a transformation in the crumb matrix occurred resulting in weak internal bonds which stabilize the cake structure. Such bonds, once broken, cannot reform. Springiness showed a decrease overcome 30% PEM, while resilience and adhesiveness showed a random variation with PEM incorporation. Similar texture observations were reported when different nut-flours, rich in fiber and oil content, were included in cake-like formulations. For example, Jia, Kim, Huang, and Huang (2008), who studied wheat flour replacement by almond flour in Chinese mooncake, reported that hardness drastically decreased as the amount of almond flour increased. In addition, the inclusion of red ginseng marc powder to muffin formulation resulted in hardness, adhesiveness, and chewiness reduction (Jung, Oh, & Kang, 2015).

These observations are related with our findings in image analysis. Texture and pore size distribution of the matrix are related since we observed a softer structure when PEM was added. From C to P40 more pores were developed and up to 30% the size of the pores was increased (higher D [4,3], Table 1). Also is important to remark that oil and fiber from PEM addition have a plasticizing effect resulting into a matrix modification. As in P40 that pore distribution revealed a significantly different structure with bigger pores (probably from coalescence or collapsed structure) leading to a softer texture.

3.3. Sensorial assays

For sensory analysis three formulations were chosen: C, as a control and P20 and P30, as PEM added muffins, since both formulations showed better physicochemical characteristics, such as higher crumb moisture, product height and, and less hard but more cohesive crumb. Results for acceptance tests are shown in Table 4. As it can be seen, pecan nut expeller addition to a traditional muffin formulation had no significant effect on sensorial appearance and color. This means that consumers found both products appearance and color equally satisfying. When sensory firmness was correlated with textural

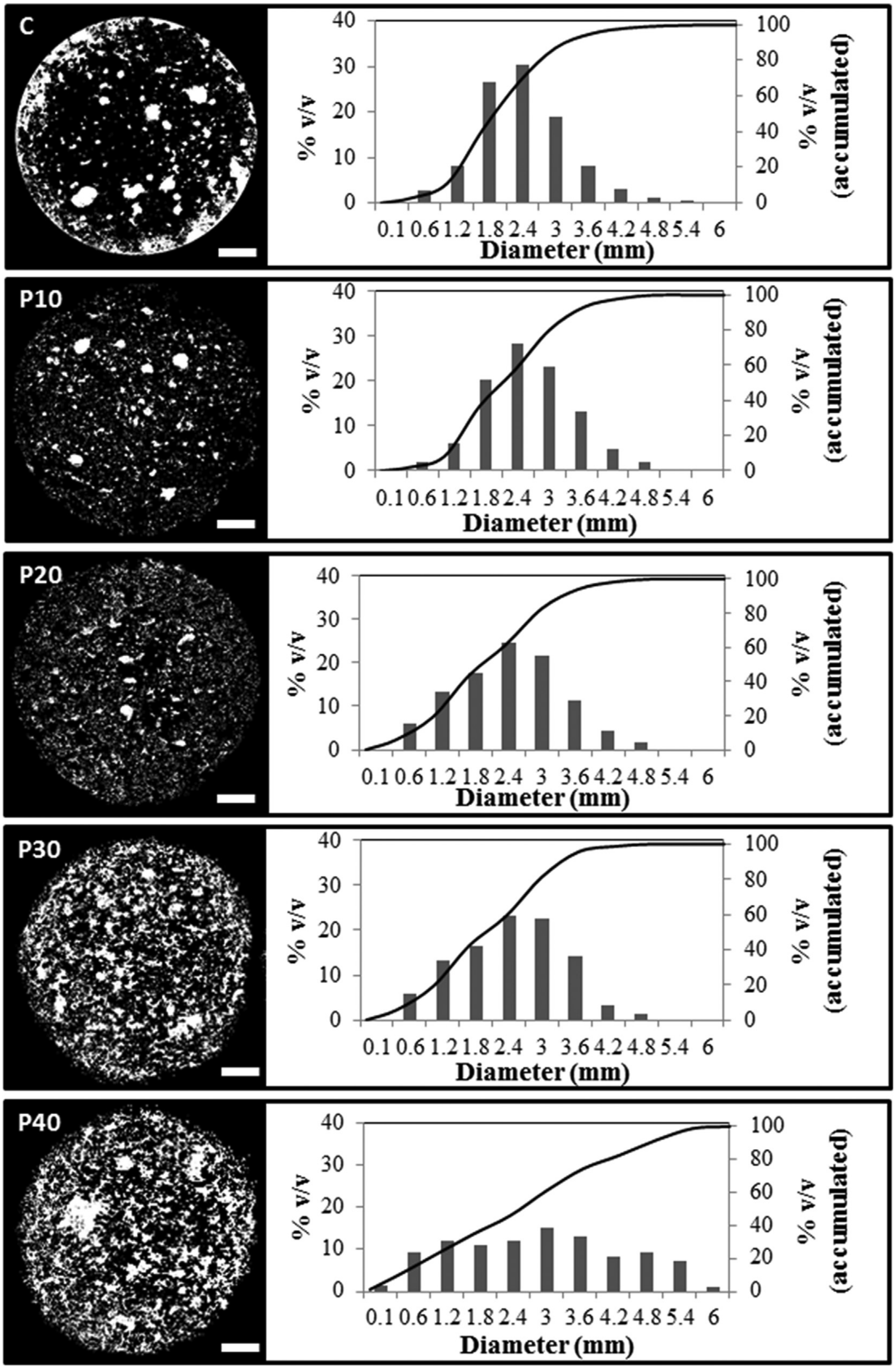

Fig. 1. Cross sectional images and pore size distribution (% v/v) of muffins with 10, 20, 30, and 40 g/100 g of wheat flour replacement with pecan nut expeller (P10, P20, P30, P40, respectively) and control without pecan nut expeller (C); white bars indicate 1 cm.

parameters (Table 3), negative correlations with hardness ($R = -0.998$, $P < 0.001$) and chewiness ($R = -0.992$, $P < 0.01$) were found, which indicates that consumers preferred softer products (P20 and P30). In the case of moisture perceived by panelists a direct correlation with crumb moisture was observed (Table 1, $R = 0.999$ $P < 0.001$). Taste and acceptability scores also increased with expeller addition. Similarly acceptability was significantly correlated with several crumb characteristics, as moisture ($R = 0.995$,

Table 2
Color analysis of muffin crust and crumb.

Code	Crust			Crumb			
	L*	a*	b*	L*	a*	b*	BI
C	62.9^{a} (1.6)	1.1^{c} (1.8)	20.9^{a} (1.8)	64.7^{a} (0.6)	-2.4^{d} (0.1)	17.5^{a} (0.3)	27.5^{d} (0.7)
P10	61.9^{b} (0.2)	3.1^{b} (0.3)	19.1^{a} (1.7)	55.5^{b} (0.6)	3.8^{c} (0.2)	13.1^{b} (0.2)	31.1^{c} (0.4)
P20	54.6^{cd} (0.4)	4.0^{ab} (0.4)	14.8^{bc} (1.6)	48.1^{c} (0.4)	5.5^{b} (0.2)	11.5^{c} (0.3)	34.9^{b} (0.8)
P30	55.0^{c} (0.6)	3.8^{ab} (0.3)	15.8^{b} (1.2)	44.8^{d} (0.2)	5.3^{b} (0.2)	10.4^{d} (0.2)	34.2^{b} (0.8)
P40	50.1^{d} (0.4)	5.0^{a} (0.5)	13.6^{c} (1.7)	40.0^{e} (0.3)	6.4^{a} (0.2)	9.5^{d} (0.2)	38.0^{a} (0.9)

* Different letters in the same column, indicate significant differences ($P < 0.05$).
** 2 Batches, 6 replicates each.
Codes: control formulation (C), formulation with 10, 20, 30, and 40% wheat flour replaced with pecan nut expeller (P10, P20, P30, P40, respectively).

Table 4
Sensorial evaluation of muffins.

Item	Muffin formulation		
	C	P20	P30
Appearance	7.1 (0.3)	7.4 (0.3)	7.7 (0.5)
Color	7.1 (0.2)	7.1 (0.4)	7.6 (0.5)
Firmness	6.9^{b} (0.2)	7.6^{a} (0.3)	7.6^{a} (0.5)
Crumb moisture	6.9^{b} (0.2)	7.4^{ab} (0.3)	7.8^{a} (0.5)
Taste	6.5^{b} (0.3)	7.4^{a} (0.3)	7.8^{a} (0.5)
Overall acceptability	6.7^{b} (0.2)	7.6^{a} (0.3)	7.9^{a} (0.5)
Color (%)			
Below JAR	50.0 (−1.2)	37.5 (−0.9)	8.3 (−)
JAR	43.8	47.9	62.5**
Above JAR	6.3 (−)	14.6 (−)	29.2 (−0.3)
Firmness (%)			
Below JAR	25 (−2.3)	14.6 (−)	12.5 (−)
JAR	41.7	66.7**	77.1**
Above JAR	33.3 (−1.0)	18.7 (−)	10.4 (−)
Crumb moisture (%)			
Below JAR	37.5 (−0.6)	20.83 (−1.2)	16.7 (−)
JAR	37.5	62.5**	64.6**
Above JAR	25 (0.5)	16.67 (−)	18.8 (−)

* Different letters in the same column indicate significant differences ($P < 0.05$).
** Indicates higher ($P > 0.05$) JAR proportions.
*** Number of panelists: 48.
Codes: control formulation (C), formulation with 20 and 30% wheat flour replaced with pecan nut expeller (P20 and P30, respectively).
Liking attributes were scored on a 9-point hedonic scale, where 1 = dislike extremely and 9 = like extremely; just-about-right (JAR) scale was scored on a 5-point scale where −2 to −1 = below JAR, 0 = JAR, and 1 to 2 = above JAR. The JAR results indicate the percentage of assessors that selected these options; the number between parentheses is penalty score calculated when more than 20% of assessors selected this options.

$P < 0.001$), lightness ($R = -0.996$, $P < 0.001$), and chewiness ($R = -0.993$, $P < 0.001$), which means that muffins with higher moisture, darker crumb, and softer texture were the most preferred by panelists.

It is important to remark that for all studied attributes pecan nut expeller had a neutral or positive effect reaching scores always higher than 7 (like moderately).

To deeply explore PEM addition effects on sensorial color, firmness, and crumb moisture of muffins a "just-about-right" (JAR) test was performed (Rothman & Parker, 2009). Table 4 shows these results and also penalty analysis performed using data from JAR test for the same attributes. JAR results confirmed the higher acceptability of P20 and P30 formulations, showing higher JAR and lower penalty scores respect to control. 20% of WF replacement with PEM showed almost the same responses than control formulation with an important proportion of 0 (JAR) and −1 (slightly less color intensity). A replacement of 30% WF with PEM leaded to a large proportion of 0 (JAR) and +1 (slightly excess of color intensity). Firmness showed significantly higher JAR frequency for P20 and P30, indicating a narrower distribution than control, centered on JAR score (0). This effect was reflected in high penalty scores for control formulation in both too soft and too hard section. Panelists preferred softer samples, and this was achieved when PEM was included leading to a very high proportion of JAR score and negligible.

Finally crumb moisture perception showed a similar pattern than firmness, where addition of both PEM levels increased the frequency of its perception by panelists.

As can be seen P30 color JAR score was significantly higher than others formulations, while P20 and P30 firmness and crumb moisture JAR scores were higher than C. Nevertheless 20% of PEM addition did not solve the too dry penalty (below JAR). This issue was finally solved with 30% of PEM obtaining marginal below and above JAR proportions.

4. Conclusion

These results indicated that pecan nut expeller meal with high fiber and monounsaturated fatty acids contents could be a good industrial and nutritional alternative to wheat flour in bakery products. In addition, as a by-product of pecan nut oil industry, its inclusion in food products would have economic benefits. Instrumental and sensorial data showed that the optimum range of wheat flour replacement with pecan nut expeller meal in a basic muffin formulation would be between 20 and 30%.

Acknowledgements

This research was supported by Consejo Nacional de Investigaciones Científicas y Tecnológicas (CONICET, Argentina) PIP0546, Agencia Nacional de Promoción Científica y Tecnológica (ANPCyT) PICT-2015-0344 and PICT-2015-2637, and Universidad Nacional de La Plata X-

Table 3
Texture parameters of muffin formulations.

Code	Hardness (N)	Chewiness (N)	Cohesiveness (J/J)	Springiness (mm/mm)	Resilience (J/J)	Adhesiveness ($Jx10^{-3}$)
C	7.8^{a} (0.3)	2.59^{a} (0.12)	0.413^{b} (0.004)	0.801^{a} (0.011)	0.197^{b} (0.005)	77.9^{b} (15)
P10	6.1^{b} (0.2)	2.12^{b} (0.07)	0.418^{b} (0.002)	0.825^{a} (0.007)	0.200^{b} (0.005)	132.0^{a} (19)
P20	4.5^{c} (0.1)	1.56^{c} (0.05)	0.427^{a} (0.001)	0.814^{a} (0.006)	0.212^{a} (0.003)	34.0^{c} (10)
P30	3.8^{d} (0.2)	1.22^{d} (0.06)	0.431^{a} (0.002)	0.747^{b} (0.007)	0.193^{b} (0.003)	56.1^{bc} (12)
P40	3.2^{d} (0.2)	1.00^{d} (0.06)	0.434^{a} (0.002)	0.719^{b} (0.007)	0.188^{b} (0.003)	68.5^{bc} (12)

* Different letters in the same column indicate significant differences ($P < 0.05$).
** 2 Batches, 6 replicates each.
Codes: control formulation (C), formulation with 10, 20, 30, and 40% wheat flour replaced with pecan nut expeller (P10, P20, P30, P40, respectively).

728. In addition, authors thank NUCANA S.A. (Entre Ríos, Argentina), Molino Campodónico (La Plata, Argentina), Ovobrand (Brandsen, Argentina), and Saporiti (Buenos Aires, Argentina) for ingredients provided.

References

Ajila, C., Leelavathi, K., & Rao, U. P. (2008). Improvement of dietary fiber content and antioxidant properties in soft dough biscuits with the incorporation of mango peel powder. *Journal of Cereal Science, 48*(2), 319–326.

Aliani, M., Ryland, D., & Pierce, G. N. (2011). Effect of flax addition on the flavor profile of muffins and snack bars. *Food Research International, 44*(8), 2489–2496.

Arora, A., & Camire, M. E. (1994). Performance of potato peels in muffins and cookies. *Food Research International, 27*(1), 15–22.

Beuchat, L. R. (1977). Functional and electrophoretic characteristics of succinylated peanut flour protein. *Journal of Agricultural and Food Chemistry, 25*(2), 258–261.

Bourne, M. C. (1978). Texture profile analysis. *Food Technology, 32*, 62–66 72.

Brennan, J. G., & Bourne, M. C. (1994). Effect of lubrication on the compressionbehaviour of cheese and frankfurters. *Journal of Texture Studies, 25*, 139–150.

Chakraborty, P. (1986). Coconut protein isolate by ultrafiltration. *Food Engineering and Process Applications, 2*(1), 308–315.

Corral, M. L., Cerrutti, P., Vázquez, A., & Califano, A. (2017). Bacterial nanocellulose as a potential additive for wheat bread. *Food Hydrocolloids, 67*(1), 189–196.

Damodaran, S. (2008). Amino acids, peptides, and proteins. In O. R. Fennema (Ed.). *Food chemistry*. Boca Raton, FL: CRC Press.

Demirkesen, I., Sumnu, G., & Sahin, S. (2013). Quality of gluten-free bread formulations baked in different ovens. *Food and Bioprocess Technology, 6*(3), 746–753.

Gómez, M., Moraleja, A., Oliete, B., Ruiz, E., & Caballero, P. A. (2010). Effect of fibre size on the quality of fibre-enriched layer cakes. *LWT-Food Science and Technology, 43*(1), 33–38.

Gómez, M., Oliete, B., Caballero, P., Ronda, F., & Blanco, C. (2008). Effect of nut paste enrichment on wheat dough rheology and bread volume. *Food Science and Technology International, 14*(1), 57–65.

Grigelmo-Miguel, N., Carreras-Boladeras, E., & Martín-Belloso, O. (1999). Development of high-fruit-dietary-fibre muffins. *European Food Research and Technology, 210*(2), 123–128.

Gularte, M. A., de la Hera, E., Gómez, M., & Rosell, C. M. (2012). Effect of different fibers on batter and gluten-free layer cake properties. *LWT-Food science and Technology, 48*(2), 209–214.

Haddad, E., Jambazian, P., Karunia, M., Tanzman, J., & Sabaté, J. (2006). A pecan-enriched diet increases γ-tocopherol/cholesterol and decreases thiobarbituric acid reactive substances in plasma of adults. *Nutrition Research, 26*(8), 397–402.

Hancock, B. (1997). *Development of pecan industry. Texas pecan handbook.* Texas Agricultural Extension Service1–7.

Jia, C., Kim, Y. S., Huang, W., & Huang, G. (2008). Sensory and instrumental assessment of Chinese moon cake: Influences of almond flour, maltitol syrup, fat, and gums. *Food Research International, 41*(9), 930–936.

Jung, Y. M., Oh, H., & Kang, S. T. (2015). Quality characteristics of muffins added with red ginseng marc powder. *Journal of the Korean Society of Food Science and Nutrition, 44*(7), 1050–1057.

Kornsteiner, M., Wagner, K.-H., & Elmadfa, I. (2006). Tocopherols and total phenolics in 10 different nut types. *Food Chemistry, 98*(2), 381–387.

Lakshminarayan, K., Solid, C. A., Collins, A. J., Anderson, D. C., & Herzog, C. A. (2006). Atrial fibrillation and stroke in the general medicare population a 10-year perspective (1992 to 2002). *Stroke, 37*(8), 1969–1974.

Lebesi, D. M., & Tzia, C. (2011). Effect of the addition of different dietary fiber and edible cereal bran sources on the baking and sensory characteristics of cupcakes. *Food and Bioprocess Technology, 4*(5), 710–722.

Marchetti, L., Romero, L., Andrés, S. C., & Califano, A. N. (2017). Characterization of pecan nut expeller cake and effect of storage on its microbiological and oxidative quality. *Grasas Y Aceites, 68*(4), e226.

Martínez-Cervera, S., Salvador, A., Muguerza, B., Moulay, L., & Fiszman, S. (2011). Cocoa fibre and its application as a fat replacer in chocolate muffins. *LWT-Food Science and Technology, 44*(3), 729–736.

Masoodi, F., Sharma, B., & Chauhan, G. (2002). Use of apple pomace as a source of dietary fiber in cakes. *Plant Foods for Human Nutrition, 57*(2), 121–128.

Mildner-Szkudlarz, S., Siger, A., Szwengiel, A., & Bajerska, J. (2015). Natural compounds from grape by-products enhance nutritive value and reduce formation of CML in model muffins. *Food Chemistry, 172*(1), 78–85.

Nasar-Abbas, S. M., & Jayasena, V. (2012). Effect of lupin flour incorporation on the physical and sensory properties of muffins. *Quality Assurance and Safety of Crops & Foods, 4*(1), 41–49.

O'Shea, N., Doran, L., Auty, M., Arendt, E., & Gallagher, E. (2013). The rheology, microstructure and sensory characteristics of a gluten-free bread formulation enhanced with orange pomace. *Food & Function, 4*(12), 1856–1863.

Paraskevopoulou, A., & Kiosseoglou, V. (1997). Texture profile analysis of heat-formed gels and cakes prepared with low cholesterol egg yolk concentrates. *Journal of Food Science, 62*(1), 208–211.

Pinheiro do Prado, A. C., Monalise Aragão, A., Fett, R., & Block, J. M. (2009). Antioxidant properties of pecan nut [Carya illinoinensis (Wangenh.) C. Koch] shell infusion. *Grasas Y Aceites, 60*(4), 330–335.

Rothman, L., & Parker, M. J. (2009). *Just about right (JAR) scales: Design, usage, benefits and risks.* West Conshohocken PA: ASTM International.

Salvador, A., Podestá, R., Block, J., & Ferreira, S. (2016). Increasing the value of pecan nut [Carya illinoinensis (Wangenh) C. Koch] cake by means of oil extraction and antioxidant activity evaluation. *The Journal of Supercritical Fluids, 116*(1), 215–222.

Struck, S., Gundel, L., Zahn, S., & Rohm, H. (2016). Fiber enriched reduced sugar muffins made from iso-viscous batters. *LWT-Food Science and Technology, 65*(1), 32–38.

Sudha, M., Baskaran, V., & Leelavathi, K. (2007). Apple pomace as a source of dietary fiber and polyphenols and its effect on the rheological characteristics and cake making. *Food Chemistry, 104*(2), 686–692.

Ureta, M. M., Olivera, D. F., & Salvadori, V. O. (2014). Quality attributes of muffins: Effect of baking operative conditions. *Food and Bioprocess Technology, 7*(2), 463–470.

Yang, T., Bai, Y., Wu, F., Yang, N., Zhang, Y., Bashari, M., ... Xu, X. (2014). Combined effects of glucose oxidase, papain and xylanase on browning inhibition and characteristics of fresh whole wheat dough. *Journal of Cereal Science, 60*(1), 249–254.

Yang, J., Liu, R. H., & Halim, L. (2009). Antioxidant and antiproliferative activities of common edible nut seeds. *LWT-Food Science and Technology, 42*(1), 1–8.