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Mesquite (*Prosopis alba*) flour as a novel ingredient for obtaining a "panettone-like" bread. Applicability of part-baking technology

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ABSTRACT

Mesquite flour is obtained by grinding the pods of *Prosopis spp.*, a leguminous tree widely distributed in several American countries. This flour contains valuable nutritional and functional components (minerals, fiber) that can contribute to food enrichment. In the present work, mesquite flour (MF) (150–350 g/kg) was blended with wheat flour (WF) (850-650 g/kg) to obtain composite sweet breads. The replacement with MF diminished the resilience (up to 33%) and increased the adhesiveness (up to 20%) of doughs. Higher values of dynamic moduli were obtained when MF level in composite dough was increased. Consequently, leavening was hindered by the presence of MF and thus lower maximum volumes were attained. Concomitantly, when comparing to the bread without MF, lower heights (up to 41% less) and firmer crumbs (up to 60%) were obtained after baking. Crumb microstructure showed smaller and more irregular alveoli with thicker walls when mesquite flour was added. However, sensory analysis revealed a good degree of acceptability for these composite breads, particularly at 250 g/kg replacement level. Part-baking technology was successfully used in formulations with MF since after eight weeks of frozen storage (−18 °C) no changes were observed in the texture parameters of breads in comparison with non-frozen bread.

1. Introduction

Mesquite flour (MF) is a sweet and aromatic product obtained by grinding the whole ripe fruit of mesquite tree (*Prosopis spp.*). It is high in dietary fiber, minerals and sucrose, and has a slightly lower content of proteins than flours from cereals such as wheat and corn. Other flours can also be obtained from mesquite by grinding the seeds or the rest of the pods (Bigne, Puppo, & Ferrero, 2016b; Felker, Takeoka, & Dao, 2013). Mesquite is used mainly as flour to obtain a wide range of regional food products such as alcoholic (by fermentation of whole pods) and nonalcoholic beverages, leavened and non-leavened breads and cakes (mixed with other cereal flours) and is also used as coffee and chocolate substitute (Barba De La Rosa, Frías-Hernández, Olalde-Portugal, & Castañeda, 2006; Bravo, Grados, & Saura-Calixto, 1994). The amino acidic composition of mesquite proteins is nutritionally complementary with that of cereal proteins (Felker & Bandurski, 1977). Taking the latter into account and also its high content of fiber and minerals, this flour has a good potential to be used in healthy cereal-based formulations.

MF was previously tested in simple bread formulations. MF addition in non-sweet breads modified their sensory characteristics and technological quality (specific volume, crumb texture and porosity). However, the fiber content was significantly increased by MF addition allowing obtaining fiber enriched breads (Bigne, Puppo, & Ferrero, 2016a). Taking into account the particular color and flavor conferred by MF, it was considered that these characteristics would make it a good ingredient for sweet bread/cake formulations. Sweet bakery comprises a large number of products due to the great variety of ingredients that can be used in it. The panettone is an Italian festive sweet cake that belongs to a wide range of biologically leavened sweet cakes. It is characterized by its richness of sucrose (300–400 g/kg of wheat flour-WF) and fat matter (200–300 g/kg of WF). Its water content is about 250–350 g/kg, and part of this water amount is contributed by eggs. Traditionally, candied fruits and raisins are also added. The customary breadmaking procedure includes two mixing and at least two leavening (of several hours) steps. This leads to obtaining a product of high specific volume (similar to that of traditional breads) with a light and soft crumb (Pagani, Lucisano, & Mariotti, 2014). The complexity of the formulation and the preparation procedure (several steps and long leavening periods) of this kind of product makes its wide and continuous supply difficult. Part-baking, a bake-off technology (BOT) could contribute to facilitate the provision and availability of the fresh

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product in minimally equipped sale points with the advantage that the supply is on demand.

BOTs include frozen doughs and part-baking techniques. In the first case the dough is typically prepared and frozen in the central factory before being distributed to the sale points where it is thawed, leavened and baked. In the second case the steps of leavening and baking (partial baking) are also centralized, and the product is distributed partially baked and frozen to the sale points, where the process is completed with a final baking (Bárcenas, Benedito, & Rosell, 2004; Giannou & Tzia, 2007).

The objectives of the present work were: (a) test MF as ingredient in a composite sweet bread (based on the traditional panettone formulation) employing different levels of wheat flour (WF) replacement, (b) analyze the applicability of part-baking technology in these formulations.

2. Materials and methodology

2.1. Materials

WF type 000 (Molino Campodónico SA, La Plata, Argentina) with a composition of (g/kg) 121.1 of proteins, 13.2 of lipids, 137.4 of moisture, 0.70 of ash, 37.4 of total dietary fiber was utilized. MF of fully mesquite pods was acquired from local producers (INTI ATUN, Santiago del Estero, Argentina) of the province of Santiago del Estero, in the northwest region of Argentina. MF has a characteristic sweet aroma and a light-brown color typical of "white" mesquite species (*Prosopis alba*), and had the following composition (g/kg): 77.5 of proteins, 13.3 of lipids, 103.4 of moisture, 26.7 of ash, 219.0 of total dietary fiber, 447.7 of sucrose, 32.2 of fructose, and 10.3 of glucose. The composition of flours was determined in our laboratory according to AACC approved methods 46-12, 44-19, 8-1 and 32-05 for proteins, moisture, ash, and total dietary fiber, respectively (AACC, 2000); lipids were determined by extraction using a Soxhlet device, and soluble sugars were determined by HPLC. For dough and bread formulations margarine (Dánica, Buenos Aires, Argentina), fresh yeast (Calsa, Buenos Aires, Argentina), fresh eggs, and sodium chloride (Celusal, Vicente López, Argentina) were also used.

2.2. Panettone-like breads with MF

2.2.1. Formulation and breadmaking procedure

The formulations evaluated are summarized in Table 1. The basic formulation was obtained through preliminary assays taking as reference the one reported by Benejam, Steffolani, and León (2009) with some modifications in the amounts of water, margarine, salt and fresh eggs, and using fresh yeast instead of dehydrated yeast. The quantity of WF, which was partially replaced by MF at four levels: 0, 150, 250 and 350 g/kg (formulations MF0, MF150, MF250 and MF350 respectively), and sugar, reduced according to the increase in the level of mesquite flour, were modified among formulations. The latter was done taking into account the high level of sugars present in MF (mainly sucrose, as mentioned in Section 2.1) in order to maintain a constant ratio of sugar/total flour (250 g/kg) in all the formulations. The breadmaking process was simplified and involved a single leavening step. The traditional process for panettone breadmaking requires several fermentation steps, and natural sourdough is commonly used (Pagani et al., 2014).

Table 1
Formulations for doughs with different mesquite flour contents.

Component	Formulation (g/kg of total flour)			
	MF0	MF150	MF250	MF350
WF	1000	850	750	650
MF	0	150	250	350
water	240	240	240	240
sugar	250	168	113	58
margarine	200	200	200	200
liquid egg	170	170	170	170
salt	10	10	10	10
fresh yeast	30	30	30	30

WF: wheat flour; MF: mesquite flour; MF0, MF150, MF250, MF350: formulations with 0, 150, 250 and 350 g of mesquite flour/kg of total flour.

The fresh yeast was suspended in 100 ml of water at 30 °C with 10 g of sugar and added to the rest of the ingredients into a planetary kneader (Kenwood, Treviso, Italy). The flour/s, salt, melted margarine and the rest of the sugar were premixed for 1 min. Then the suspension of yeast, the liquid egg and the rest of the water were added and mixed for 30 min at 90 rpm. The dough obtained was allowed to rest for 10 min at room temperature covered with a polyethylene film to prevent dehydration. Two hundred g dough pieces were cut and manually formed, and placed in cylindrical molds (100 mm of diameter and 120 mm height) that were put in a fermentation cabinet (Brito Hnos., Los Polvorines, Argentina) at 30 °C during the optimal fermentation time for each formulation. Those times were 320.5 min, 293.7 min, 285.7 min and 231.1 min for doughs MF0, MF150, MF250 and MF350 respectively, and were determined as described in Section 2.2.3. After fermentation process, the leavened dough were baked for 40 min at 180 °C in an electric oven (Ariston, Fabriano, Italy), obtaining fully baked breads (FB) (see Table 2).

2.2.2. Rheological characterization of sweet composite doughs

Doughs prepared as described in Section 2.2.1, without yeast incorporation (to prevent leavening during the measurement), with different WF replacements by MF were rheologically characterized by small and large deformation tests.

2.2.2.1. Small amplitude oscillatory tests. Fresh dough discs were analyzed in a controlled stress rheometer RS600 (Haake, Waltham, MA, USA) with rough surface parallel plates. A gap of 2 mm between plates was used. Strain sweep tests were performed to obtain the linear viscoelastic range, and then frequency sweep tests were performed (0.005–100 Hz) at 25 °C. Measurements of G′, G″, and tan δ were obtained at a frequency of 1 Hz. Assays were performed by triplicate.

2.2.2.2. Texture profile analysis (TPA). A Texture Analyzer TA.XT2i (Stable Micro Systems, Godalming, U.K.) provided with a 245.3 N load cell was used. Discs of 30 mm diameter and 10 mm thickness were subjected to two consecutive compressions up to 40% of the initial height using a flat probe (SMSP/75) of 75 mm diameter and 1 mm s^{-1} crosshead speed. Measurements of force as a function of time were recorded, and texture profiles were analyzed to obtain the parameters of hardness (maximum force at the first peak), springiness (ratio between the distance corresponding to the second compression and the original compression distance), resilience (ratio between the area corresponding to the withdrawal of the first compression and the area of the first compression), and cohesiveness (area of the second peak with respect to the area of the first peak). Twelve assays were performed for each formulation.

2.2.3. Fermentation curves - determination of optimal fermentation times

Rounded pieces of 50 g of dough prepared as previously described (Section 2.2.1) were placed in graduated cylinders and leavened in a chamber at 30 °C and 50–60% relative moisture. The increase in volume of the dough was recorded across time, and data were plotted with OriginPro 8 (Origin Lab Corporation, Northampton, USA) software and fitted with Boltzmann sigmoidal function (eq. (1)) as described by Bigne et al. (2016a). The dependent variable ΔV corresponds to volume increase (cm^3), the independent variable t is the time (min), and parameters A, ΔV_{max}, B and C are fitting constants. Parameter ΔV_{max} corresponds to the maximum increase in volume. Optimal fermentation

Table 2
Nomenclature for partial and fully baked breads and treatment descriptions.

	Grade of baking	Treatment	Treatment description
Without freezing	Partial	**PB:** Part-Baked	partially baked breads, 20 min at 180 °C
	Complete	**FB:** Fully Baked	fully baked breads, 40 min at 180 °C
		PB + fB: Part-Baked and finished Baking	partially baked breads and finished baking: 20 min at 180 °C + cooled at room temperature 1 h + 20 min at 180 °C
With freezing	Partial	**PBFr:** Part-Baked and Frozen	partially baked breads (20 min at 180 °C) + frozen and stored at −18 °C (variable times) + thawed at room temperature
	Complete	**PBFr + fB:** Part-Baked, Frozen and finished Baking	partially baked breads (20 min at 180 °C) + frozen and stored at −18 °C + thawed + finished baking (20 min at 180 °C).

time (t_{op}) was calculated as the time to reach three quarters of the maximum volume increase (0.75 x ΔV_{max}).

$$\Delta V = \Delta V_{max} + (A - \Delta V_{max})/(1 + \exp((t - B)/C)) \qquad (1)$$

2.2.4. Bread quality

The baked pieces of bread were left to rest for 1 h at room temperature before conducting the following tests:

2.2.4.1. Bread height. Bread height was determined as the length between the bread base and the midpoint of the upper surface. At least 8 pieces of bread were measured.

2.2.4.2. Crust and crumb color. Parameters L*, a* and b* were determined in the crust and crumb of sweet breads using a colorimeter Minolta CR-400 (Minolta, Osaka, Japan) based on CIELab color space. L* (lightness) varies between 0 (black) and 100 (white), a* takes negative (greenish) or positive (reddish) values, and b* also varies from negative (bluish) to positive (yellowish). Eight replicates at least per sample were done.

2.2.4.3. Crumb structure. Two slices from the middle part of breads were photographed, and pictures were analyzed with ImageJ 1.48q software (National Institutes of Health, Bethesda, USA) to obtain the number, mean size, area occupied and circularity of alveoli. For these measurements, a lower limit was fixed for alveolus size (0.2 mm^2). Alveoli with sizes greater than 30 mm^2 were also disregarded for the calculation of mean size and circularity. At least 8 bread slices were analyzed for each formulation.

2.2.4.4. Scanning electron microscopy (SEM). Portions of crumb of fresh FB breads were frozen at −80 °C until freeze-dried. Dehydrated samples were cut into smaller portions and coated with gold particles. A scanning electron microscope Jeol JSM-6360 LV (Jeol, Tokyo, Japan) was employed to obtain images of different fields at various magnifications.

2.2.4.5. Crumb texture. From the middle part of each bread, two slices 2 cm thick were obtained, and from each one 3 discs of 3 cm diameter were analyzed. The texture profile analysis of the crumb of breads was performed using a texture analyzer TA.XT2i (Stable Micro Systems, Godalming, U.K.) provided with a 245.3 N load cell. Slices were subjected to a double compression cycle up to 40% of the original height using a flat probe (SMSP/75) of 75 mm diameter and 1 mm s^{-1} crosshead speed. At least twelve slices for each formulation were tested. The parameters determined (as described in Section 2.2.2) were: hardness, cohesiveness and springiness.

2.2.4.6. Crumb moisture and water activity. Crumb samples were dried in an oven at 103 °C until constant weight according to the official method AACC 44-15A. Measurements were made by triplicate.

The water activity of the crumb was measured in AquaLab series 3 (Decagon Devices, Inc. Pullman, USA) equipment at 25 °C for the different formulations at least by quadruplicate.

2.2.5. Sensory analysis

A panel with consumers (non-trained people) between 25 and 60 years old (36 people) was used to evaluate the acceptability of sweet breads added with different levels of MF. Each panelist received three samples of panettone-like sweet bread (corresponding to MF150, MF250 and MF350) codified and sorted randomly. They were asked to indicate the level of satisfaction using hedonic scales of 9 points (1 = dislikes much, 9 = likes much) for the following parameters: appearance, color, aroma, texture, sweetness, flavor, and general acceptability. They were also asked about the frequency with which they consumed products derived from mesquite.

2.2.6. Composition analysis of breads

Moisture (AACC 44-15A), ash (AACC 08-01), lipids (AACC 30-10), proteins by Kjeldahl method (AACC 46-12), and total dietary fiber by enzymatic method (AACC 32-05) were determined. Assays were performed at least in duplicate.

2.3. Part-baking procedure

Doughs were prepared as described in Section 2.2, but baking was performed at 180 °C up to 20 min. Part-baked breads (PB) were unmolded and cooled at room temperature for 60 min.

Then, breads were frozen in a chamber with forced air ventilation at −30 °C for 120 min (enough to reach −15 °C at the bread center). The frozen part-baked breads (PBFr) were stored in individual polyethylene bags at −20 °C.

2.3.1. Storage tests

At different storage times (2, 4 and 8 weeks) the PBFr were thawed at room temperature for 60 min, baked at 180 °C for 20 min and cooled at room temperature for 60 min to obtain the Part-Baked, Frozen and finished Baking breads (PBFr + fB). The quality parameters of PBFr after thawing and PBFr + fB were analyzed as described for fresh breads (Section 2.2.3). Besides, changes during storage were analyzed by differential scanning calorimetry (DSC). For each formulation, two non-frozen samples were used as controls: (a) part-baked breads (20 min at 180 °C) (PB), and (b) part-baked and finished baking (20 min at 180 °C, cooled for 60 min and finished baking for 20 min at 180 °C) (PB + fB). A summary of the nomenclature for the different treatments is shown in Table 2.

2.3.2. Differential scanning calorimetry

Gelatinization and amylopectin crystallization during bread storage were evaluated by DSC. Crumb samples were heated at 10 °C/min from room temperature up to 140 °C in a differential scanning calorimeter equipment Q100 (TA Instruments, New Castle, DE, USA). As a reference, an empty pan was used.

Table 3
Texture parameters obtained for composite wheat flour-mesquite flour doughs.

Sample	Hardness (N)	Springiness (-)	Resilience (-)	Cohesiveness (-)	Adhesiveness (N*s)
MF0	1.5^{b}	0.911^{b}	0.099^{c}	0.76^{a}	3.9^{a}
MF150	1.6^{c}	0.919^{c}	0.090^{b}	0.77^{a}	4.3^{b}
MF250	1.6^{bc}	0.923^{c}	0.074^{a}	0.77^{a}	4.6^{c}
MF350	1.2^{a}	0.899^{a}	0.066^{a}	0.77^{a}	4.9^{d}
PSD	0.1	0.008	0.009	0.01	0.2

MF0, MF150, MF250, and MF350: formulations with 0, 150, 250 and 350 g of mesquite flour/kg of total flour; PSD: Pooled Standard Deviation. Mean values from at least twelve measurements are reported. Different letters within the same column indicate significant differences by LSD test ($p < 0.05$).

2.4. *Statistical analysis*

ANOVA was performed to determine significant effects of treatments when necessary, and the LSD test was applied to compare mean values. The software Statgraphics Centurion XV version 2.15.06 (StatPoint Technologies, Inc. Warrenton, USA) was used to perform the analysis.

3. Results and discussion

3.1. *Rheological characteristics of doughs*

MF addition markedly influenced the texture profile of dough (Table 3). The doughs obtained were soft and sticky, which makes their handling difficult. MF150 and MF250 were harder and more elastic than the dough without mesquite, but MF350 was softer and significantly less elastic. Resilience (instant elasticity) progressively decreased when MF level was increased. No significant modifications were found in cohesiveness. Adhesiveness increased progressively when increasing the replacement of WF by MF.

The behavior in hardness and springiness was similar and is the result of the combination of some opposite factors. It was previously reported that an increase in the MF level in composite WF-MF doughs increases the hardness of the system (Bigne et al., 2016b) due to MF components, for example, the high level of insoluble fiber. In the present work as MF level increased the added sugar decreased (Table 1), leading to a lower amount of total solid ingredients; consequently the water proportion resulted increased and the dough became softer. Besides, the loss in resilience can be associated with the formation of a poorer protein network that affects the intrinsic capacity of the dough to recover fast after the compression. The cohesiveness can be defined as the internal capacity of the sample to remain integrated. Non-loss of cohesiveness when replacing wheat proteins by MF-components is a positive aspect since cohesiveness usually diminishes when diluting gluten in composite breads. This favorable effect can be associated with the presence of egg proteins, which have well-known functional properties that help to maintain the wholeness of food structures (Stadelman, 1999).

Fig. 1 shows the mechanical spectra for composite WF-MF doughs. All formulations exhibit a solid viscoelastic behavior with higher values of the elastic modulus (G') than the viscous modulus (G") for the frequency range studied (0.05–100 Hz). The observed behavior is typical of wheat doughs (Correa, Pérez, & Ferrero, 2011) or composite wheat/legume doughs (Roccia, Ribotta, Ferrero, Pérez, & León, 2012).

Significant increases in both moduli were verified when the replacement with MF was 250 g/kg or higher. On the other hand, at 1 Hz $\tan \delta$ was higher in MF0 (0.389 ± 0.006) than in doughs with addition of MF (0.369 ± 0.008, 0.372 ± 0.002 and 0.358 ± 0.003 for MF150, MF250 and MF350, respectively) indicating that MF increases the elastic behavior with respect to the viscous one. Nevertheless, no significant differences were found in $\tan \delta$ at higher frequencies for the different formulations.

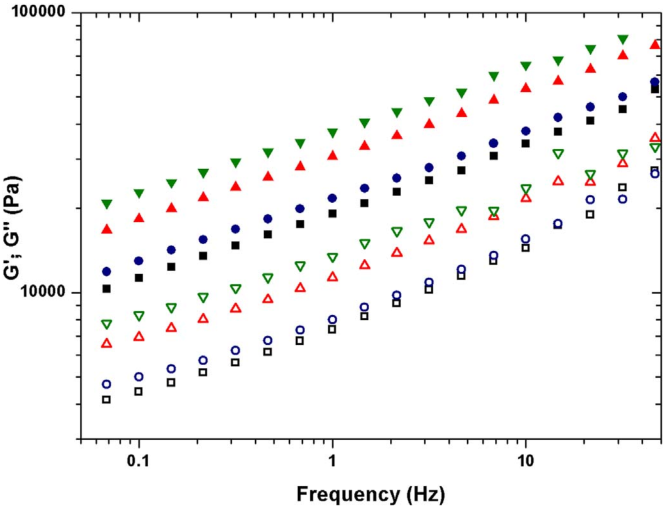

Fig. 1. Mean values of elastic (G′, filled symbols) and viscous (G″, void symbols) moduli as function of frequency for doughs containing per kg of total flour: 0 g (■,□), 150 g (●,○), 250 g (▲,△) and 350 g (▼,▽) of mesquite flour.

As it has been reported by other authors (Janssen, Van Vliet, & Vereijken, 1996; Kim et al., 2008) not always the results from large deformation tests are in agreement with those of small deformations. According to Janssen et al. (1996) large strain properties are influenced much more strongly by dough inhomogeneities than are small strain properties. Kim et al. (2008) suggested that small deformation tests are useful for understanding microstructure and molecular interactions while large deformation tests give more practical information that can be related to dough processing.

In the present work the addition of large amounts of MF that was accompanied, as explained, by the reduction in sucrose content and the concomitant increase in water/solids ratio, led to weaker and more adhesive doughs as was observed in the assays with the texturometer (large deformation test, performed in the non-linear viscoelastic range). Lesser amounts of MF did not have such an effect or even slightly increased hardness and springiness. However, when analyzing the results from the dynamic oscillatory tests (performed within the linear viscoelastic range i.e. without structure rupture) a more expectable trend was found since G′ and G″ increased when the amount of MF in the formulation increased, in spite of the higher water/solids ratio. This would indicate that the presence of MF components, mainly fiber, and their interaction with water were more determinant on the rheological behavior at the small deformation scale, that would reflect the microstructure characteristics of the sample. Even more, the tangent of the loss angle decreased when the amount of MF increased indicating a more pronounced contribution of the dough elastic behavior.

3.2. *Technological and sensory quality of wheat-mesquite sweet bread*

3.2.1. *Optimal fermentation times*

The volume increase of the dough during fermentation is related to its intrinsic capacity to expand and retain the gas generated by the yeast activity. Doughs with adequate balance of elasticity and extensibility will reach higher volumes than those excessively elastic or extensible that leads to collapse of the structure (Gómez, Buchner, Tadini, Añón, & Puppo, 2013). Fig. 2 shows the curves obtained for volume increase (ΔV) as a function of fermentation time for control dough and MF dough. A significant decrease in ΔV_{max} (from 142.9 to 90.4 cm^{3}) was observed when increasing the MF level in the formulation (from 0 to 350 g/kg respectively). Besides, t_{op} also diminished, being (mean values ± SD) 320 ± 13 min, 294 ± 13 min, 286 ± 18 min, and 231 ± 16 min for MF0, MF150, MF250, and MF350, respectively. The

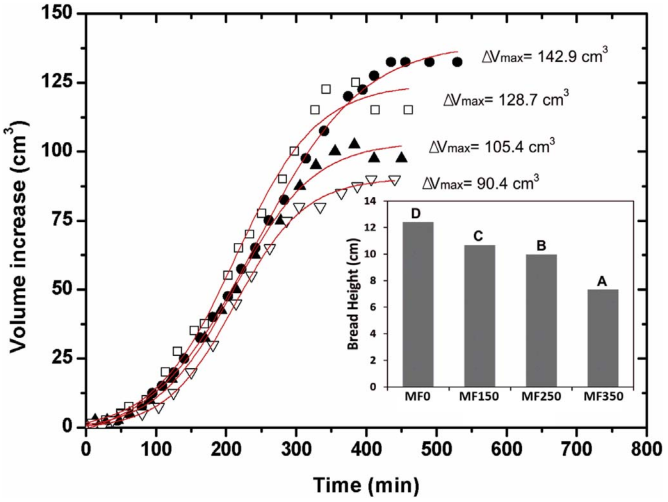

Fig. 2. Volume increase as function of time for doughs with 0, 150, 250 and 350 g of mesquite flour/kg of total flour, MF0 (●), MF150 (□), MF250 (▲), and MF350 (▽), respectively. Red curves correspond to fitting of experimental data using the Boltzmann model (Eq. (1)). ΔV_{max} values correspond to the maximum volume increase predicted by the model for each formulation. Insert: heights of fully baked breads with different amounts of mesquite flour. Different letters indicate significant differences ($p < 0.05$) between formulations. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

prolonged fermentation times (several hours) are characteristic of this and other soft sweet bakery products obtained by biological leavening (Pagani et al., 2014).

The reductions in ΔV_{max} and t_{op} can be associated with the dough rheology changes produced by the differences in the formulations. MF induces a hardening effect in dough, as previously mentioned. On the other hand, the replacement with non-wheat flours exerts a dilution effect on the gluten network that weakens dough (Doxastakis, Zafiriadis, Irakli, Marlani, & Tananaki, 2002; Mohammed, Ahmed, & Senge, 2014). Though the fat matter softens doughs (Calderón-Domínguez, Neyra-Guevara, Farrera-Rebollo, Arana-Errasquín, & Mora-Escobedo, 2003), favoring the expansion, it was reported that in high fat doughs the gluten development is reduced, rendering weaker doughs that are prone to collapse during leavening (Manohar & Rao, 1999). As mentioned in Section 3.1, the water proportion is higher when increasing WF replacement, tending to soften doughs. Thus, the rheological behavior of dough during leavening is the result of these concurrent factors. Probably, the weakened structure in highly replaced doughs begins to collapse before the maximum expansion is reached, which leads to smaller volumes and shorter fermentation times.

3.2.2. Bread quality

Height is a parameter related to specific volume in mold breads and it is an indicator of how aerated the bread crumb is. A significant reduction in height was observed as MF content increased, reaching a reduction of 41% in MF350 with respect to MF0. This trend is in accord with the reduction of ΔV_{max} during fermentation (R coefficient = 0.953). The insert in Fig. 2 shows the mean height values obtained for the different formulations.

Bread crust of MF0 breads had the highest values of L* (46 ± 2), a* (8.1 ± 0.6) and b* (7.9 ± 0.8). Among composite breads, L* significantly and progressively decreased when the level of MF increased (from 42 ± 2 for MF150 to 40 ± 3 for MF350) but no clear trends were found for a* and b* values. The brownish color of crust is mainly due to the development of products of non-enzymatic browning reaction (Maillard), favored by the loss of moisture and high temperatures during baking in the presence of sugars and proteins.

Table 4
Crumb color and texture parameters obtained for breads with different mesquite flour contents.

Sample	Crumb color			Texture Parameters		
	L*	a*	b*	Hardness (N)	Springiness (-)	Cohesiveness (-)
MF0	66^{d}	-1.3^{a}	14.7^{c}	2.4^{a}	0.89^{d}	0.56^{d}
MF150	54^{c}	3.6^{b}	13.3^{b}	3.0^{b}	0.84^{c}	0.54^{c}
MF250	49^{b}	4.5^{c}	11.4^{a}	3.3^{b}	0.81^{b}	0.49^{b}
MF350	46^{a}	5.5^{d}	11.5^{a}	6.0^{c}	0.74^{a}	0.46^{a}
PSD	2	0.2	0.4	0.6	0.02	0.02

MF0, MF150, MF250 and MF350: formulations with 0, 150, 250 and 350 g of mesquite flour/kg of total flour; PSD: Pooled Standard Deviation. Mean values from at least eight measurements are reported. Different letters within the same column indicate significant differences by LSD test ($p < 0.05$).

Crumb color parameters are shown in Table 4. The crumb of composite WF-MF breads was brownish and darker than MF0 bread crumb. The brownish color of crumb in composite breads is not due to the development of Maillard products, but probably to enzymatic reaction products since in the stages of dough preparation the darkening of the dough with the presence of MF was already observed. The polyphenol content of MF was previously reported by several authors (Bravo, Grados, & Saura-Calixto, 1998; Cardozo et al., 2010; Sciammaro, Ferrero, & Puppo, 2016) and even though there are no recent reports of polyphenol oxidase activity in mesquite, the presence of this enzymatic activity in many legumes is well known (Udayasekhara Rao & Deosthale, 1987). In this way, during dough preparation in the presence of water, browning enzymatic reactions may occur.

The texture of crumb in leavened bakery products is expected to be soft, elastic and cohesive. Values of TPA parameters are listed in Table 4. The increment of MF in the formulation led to a progressive hardening and reduction of the elasticity and cohesiveness of crumbs, which reached values 150% greater, 16.9% lower and 17.9% lower respectively for MF350 compared to MF0. Height reduction when increasing the replacement of WF by MF is related to changes in crumb texture. This is supported by high values of linear correlation coefficients when comparing height with hardness (R = 0.967, negative correlation), springiness (R = 0.997, positive correlation) and cohesiveness (R = 0.945, positive correlation). The texture changes are not just due to modifications in crumb aeration but also to the properties of cell walls. The differences in composition between MF and WF (soluble and insoluble fiber, sugar, minerals, type of protein) probably affect the rheological properties of cell walls (Bigne et al., 2016a).

Crumb moisture ranged between 328 g/kg for MF0 and 366 g/kg for MF350, and the difference was mainly due to variations in the original water proportion among formulations as discussed in section 3.1. Water activity values were between 0.89 ± 0.01 and 0.90 ± 0.01, and no significant differences were found among formulations.

3.2.3. Crumb structure

Crumb structure was analyzed at two different scales. In the case of the micrographs obtained by SEM, the observed alveoli are of diameters between 0.05 and 0.5 mm, while those observed by photographs of crumb are in the range of 0.5–6.2 mm. The results obtained from the alveolate analysis of crumb slices (Fig. 3A) are in agreement with those described for bread height and the parameters obtained from the fermentation curves (reduced dough expansion when increasing the level of MF). The average area and circularity of cells (alveoli) tended to diminish when the content of MF in the formulation increased. By SEM the morphology of bread crumb was qualitatively analyzed (Fig. 3B). A more pronounced presence of bigger cells was observed in the crumb of breads with 0 and 150 g/kg of MF than in those with higher MF content, 250 and 350 g/kg (Fig. 3B). These observations are in agreement with the results from the alveolate analysis in spite of the different scales used.

These results are related to the lower expansion capacity of MF

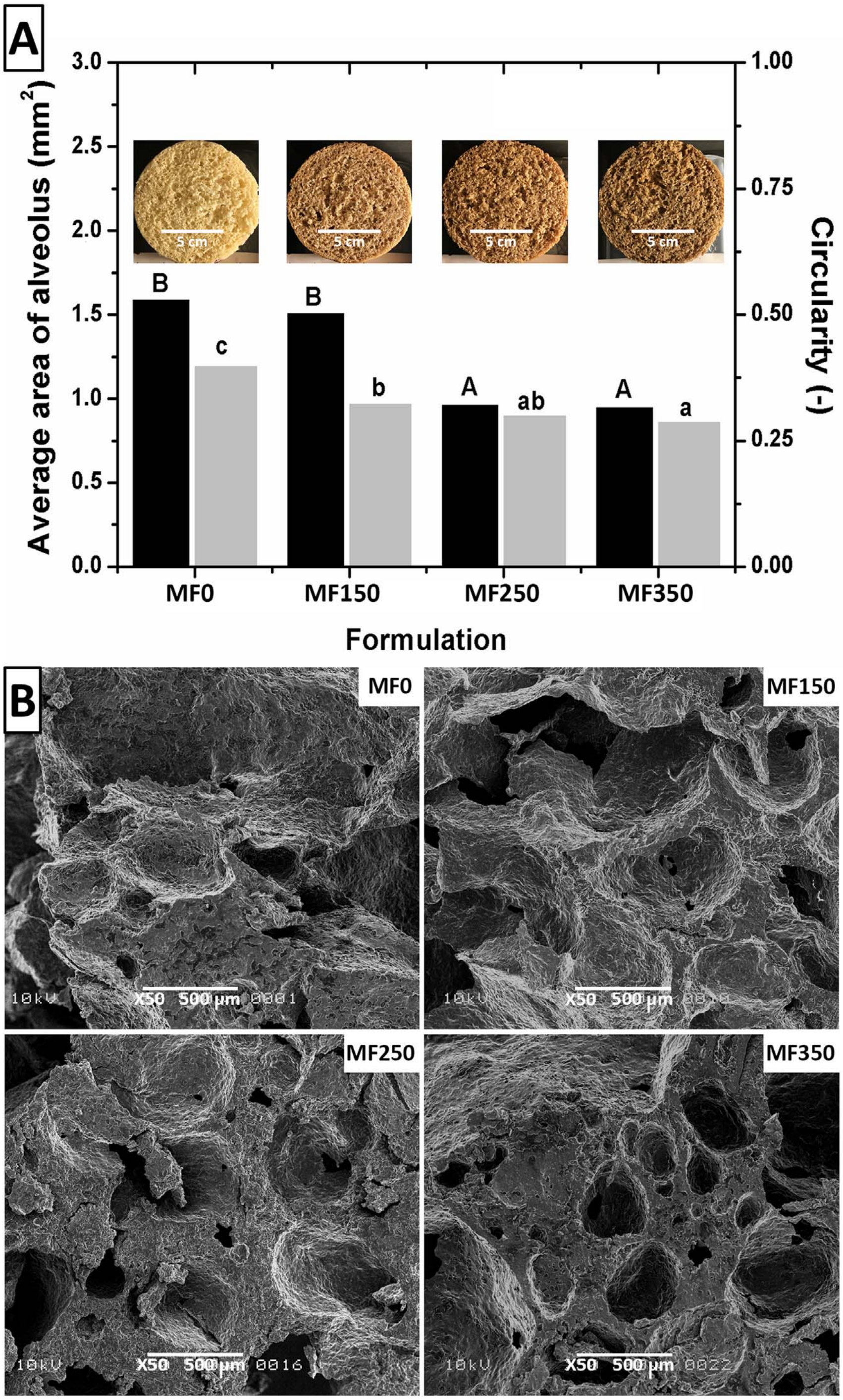

Fig. 3. A: average area (black bars) and circularity (grey bars) of alveolus for breads with 0, 150, 250 and 350 g of mesquite flour/kg of total flour (MF0, MF150, MF250 and MF350 respectively). Different letters indicate significant differences ($p < 0.05$) between formulations. B: SEM micrographs of crumb (magnifications x50) for breads with different mesquite flour contents.

doughs during fermentation, as commented in Section 3.2.1, and during the first minutes of cooking when the gas inside the dough expands by the effect of temperature. Also a more rigid structure after starch gelatinization and protein gelation (when the structure is fixed) was probably obtained in the presence of MF, which would be responsible for the deformation of alveoli.

3.2.4. *Sensory evaluation of breads*

Scores assigned by the panelists indicated that all MF sweet breads presented a good global acceptability, and no significant differences were found among the different formulations. The mean scores were 7 ± 1, 7 ± 1, and 6 ± 2 for breads with 150, 250, and 350 g/kg of MF level respectively (Fig. 4). Among the 36 panelists, 17 were occasional consumers of products with MF, 17 never consumed this kind of product, and only 2 were frequent consumers. When taking into account only those panelists that occasionally or frequently consumed MF products, the acceptability score increased for the three formulations, but no significant differences were found among them.

Nevertheless, MF250 presented the highest scores in acceptability, texture, appearance, and aroma.

3.2.5. *Composition of breads*

The results of the composition analysis are shown in Table 5. No significant differences ($p > 0.05$) in protein and lipid contents among the formulations were found. The most important results were related to the contents of total dietary fiber (TDF) and minerals, where the

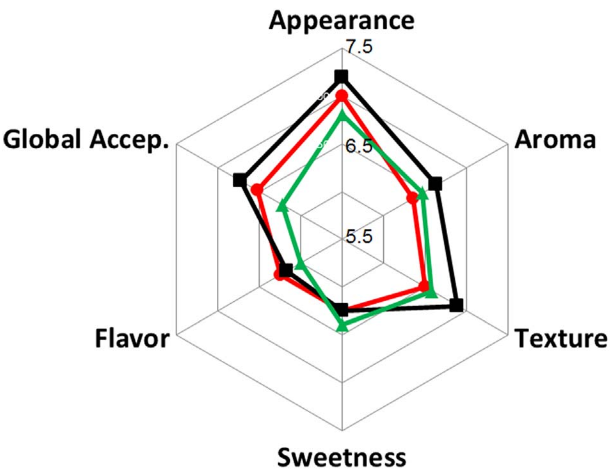

Fig. 4. Scores obtained from the sensory analysis for breads with 150 (red ●), 250 (black ■) and 350 g of mesquite flour/kg of total flour (green ▲). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 5
Composition of breads with different levels of MF.

Sample	Moisture (g/kg)	Proteins (g/kg)	Lipids (g/kg)	Minerals (g/kg)	TDF (g/kg)
MF0	328^{a}	93^{a}	69^{a}	10.2^{a}	32^{a}
MF150	345^{b}	98^{a}	69^{a}	12.5^{b}	39^{a}
MF250	342^{b}	99^{a}	73^{a}	15.6^{c}	81^{b}
MF350	369^{c}	99^{a}	68^{a}	16.9^{c}	102^{c}
PSD	3	2	10	0.5	7

MF0, MF150, MF250 and MF350: formulations with 0, 150, 250 and 350 g of mesquite flour/kg of total flour; PSD: Pooled Standard Deviation; TDF: total dietary fiber. Mean values from at least duplicates are reported. Different letters within the same column indicate significant differences by LSD test ($p < 0.05$).

higher proportion of MF increased the contents of TDF and minerals.

The mineral and TDF contents increased by 59% and 321% respectively when the replacement of WF by MF was 350 g/kg. It is important to note that breads with 250 and 350 g/kg of replacement of WF by MF could be tagged as foods "with high content of dietary fiber", according to FAO/WHO guidelines (Codex Alimentarius Commission & FAO, 2009) because they exceed the 60 g of TDF per 1 kg of product.

3.3. Part-baked breads

On the basis of the obtained results, the two formulations with higher fiber content were selected to evaluate the effect of part-baking technology. No significant differences ($p > 0.05$) in height were found between PB and PB + fB for the different formulations (data not shown), indicating that the final structure of breads would be reached during the part-baking stage. As happened for FB, breads obtained by the conventional one-step baking (section 3.2.2), the replacement of WF by MF led to a significant decrease ($p < 0.05$) in height (data not shown).

Two-way ANOVA was performed to evaluate the effect of formulation and frozen storage time on hardness, springiness and cohesiveness of PBFr and PBFr + fB crumbs.

In PBFr, frozen storage time had no significant effect ($p > 0.05$) on any texture parameter, but the type of formulation did have a significant effect ($p < 0.05$) on the three texture parameters that were analyzed; hardness increased and springiness and cohesiveness decreased with MF addition. Hardness values ranged from 1.5 N to 1.8 N for MF0 and from 4.0 N to 4.6 N for MF350; springiness was between 0.73 and 0.75 for MF0 and 0.57–0.60 for MF350; while cohesiveness values were between 0.45 and 0.47 for MF0 and 0.40–0.43 for MF350. MF250 presented intermediate values for these parameters.

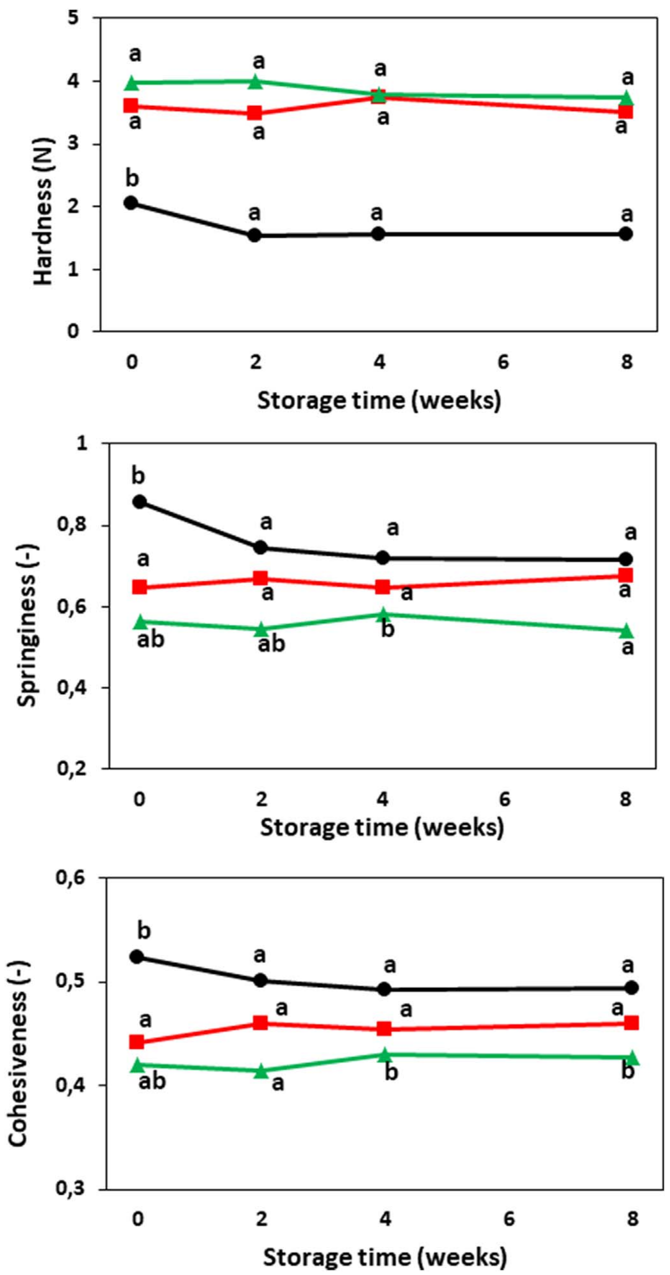

Fig. 5. Hardness (N), springiness (-) and cohesiveness (-) for Part-baked and finished Baking breads (PB + fB, storage time = 0) and Part-baked Frozen and finished Baking breads (PBFr + fB, storage time > 0) with 0 (black ●), 250 (red ■) and 350 (green ▲) g of mesquite flour/kg of total flour. Different letters indicate significant differences by LSD test ($p < 0.05$) between throughout storage time for each formulation. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Fig. 5, shows the evolution of texture parameters during storage time for PBFr + fB. Breads added with MF presented higher values of hardness and lower values of springiness and cohesiveness than MF0 for any storage time ($p < 0.05$). When comparing PB + fB (day 0 non-frozen) with PBFr + fB, the latter presented reductions in hardness, springiness and cohesiveness with frozen storage ($p < 0.05$) in the case of MF0; nevertheless MF250 and MF350 did not show significant changes in these attributes for any storage time ($p > 0.05$).

The reduction in hardness, springiness and cohesiveness for MF0 would indicate some structural damage probably caused by ice formation. The absence of significant changes in these parameters in the case of composite breads (MF250 and MF350) could indicate a better tolerance to the freezing process. The DSC analysis performed on PBFr and PBFr + fB samples revealed that no retrogradation occurred during frozen storage in any case (data not shown), because at frozen temperatures the retrogradation phenomenon is almost stopped (Bárcenas & Rosell, 2006).

Alveolar structure was analyzed in PB and PBFr breads, and no significant differences ($p > 0.05$) were found in the mean area and circularity of alveoli with frozen storage. Probably, the type of air cell wall, rich in fiber and more compact as observed in Fig. 3B, exerts a protective effect on crumb structure minimizing the damage by freezing. When comparing between formulations, the results showed the same trend discussed for FB in Section 3.2.3, i.e., reduction of the mean area and circularity of alveoli when increasing the MF content in the formulation. In the MF0 breads the mean area of alveoli and circularity were 1.5 ± 0.5 mm^2 and 0.39 ± 0.03 respectively, since for MF350 breads the values were significantly lower: 1.1 ± 0.4 mm^2 and 0.33 ± 0.02 respectively. For MF250 the results in the mean area of alveoli and circularity were intermediate.

Despite differences in composition and breadmaking procedure between the sweet breads studied in the present work and those previously studied by the same authors (Bigne et al., 2016a), some general trends could be noted. The increase in MF content led to loss of bread volume, by approximately 60% when 350 g/kg of WF was replaced by MF; the alveoli were smaller and less regular, and crumb became harder and less elastic.

4. Conclusions

The flour obtained from the pods of *Prosopis alba* (mesquite flour) demonstrated to be a versatile ingredient to be incorporated in “panettone-like” formulations. Sweet breads made with composite wheat-mesquite flour exhibited fairly good technological characteristics. Sensory tests indicated a considerable degree of acceptability since the flavor, aroma and appearance were distinctive and pleasant, particularly for the bread with a 250 g/kg replacement level. A remarkable aspect is that from a functional and nutritional point of view, these breads contained significantly higher levels of dietary fiber and minerals than the traditional sweet bread prepared with wheat flour. These results confirm the adaptability of mesquite flour to be incorporated in different bread formulations rendering healthier distinctive products. From an economical point of view, new uses of MF can contribute to the revalorization of this autochthone resource.

Additionally, the use of part-baking technology in these composite breads yielded satisfactory results and allowed obtaining products with similar quality to fresh ones even after eight weeks of frozen storage. Breads with mesquite flour were less affected by freezing and frozen storage in comparison with wheat breads. This would suggest the possibility of a protective effect of mesquite flour components, like fiber, against damage by freezing.

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