Effect of fiber fractions of prickly pear cactus (*nopal*) on quality and sensory properties of wheat bread rolls

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Abstract In this study the addition of total fiber (TF), insoluble fiber (IF), and soluble fiber (SF) from *nopal* to wheat flour used to make bread rolls was assessed. The rheological properties of dough as well as quality, texture, sensorial and physical characteristics of the crumb rolls produced were evaluated. The storage (23.50 MPa) and loss modulus (11.95 MPa) for SF-dough were the lowest indicating that a less visco-elastic behavior was obtained. Polarized light microscopy showed that a more homogeneous size and a better

distribution of starch granules were developed into SF-dough. Crumb hardness (3.25–4.78 N) and chewiness (0.31–0.81 N) of SF-rolls were lower than the control experiment (3.99–5.81 N and 0.35–1.01 N respectively). Springiness for all treatments was constant (1.0) compared with the control (1.02–0.87) for 2 days of storage. The lowest cohesiveness values (0.24–0.14) were computed by IF treatment for a similar storage time. The specific crumb volume increased by 12.46, 9.03 and 1.10 % by the addition of SF, TF and IF respectively. The lowest rate of staling was shown by SF-rolls (0.199) and it was followed by TF (0.296), IF (0.381) and control (0.458) treatments. As a result, the highest scores on quality (9.3 out of 10) and sensorial attributes (from 8.9 up to 9.7) were assigned to SF-rolls.

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Introduction

Bread, due to its low cost and special characteristics, is considered a staple food, which is consumed daily all over the world. Although in Mexico the per capital daily intake of bakery products is lower (33.5 kg) than in Europe (80 kg) or South America (70 kg), its low cost and wide availability makes them suitable for the development of new functional foods. The bread roll, better known in Mexico as *bolillo*, has the characteristic that could be filled with any kind of food, so that almost 90 % of population in Mexico consume this product at least once a day.

Mexico is the main producer of prickly pear cactus stems around the world (800,000 ton/year). Due to its high dietary fiber (DF, 40–60 g/100 g dry weight) and phytochemicals content, apart from its biofunctional activity, this crop has

become a prospect to fortify foods to take advantage of its prebiotic activity (Guevara-Arauz et al. 2011).

According to AOAC, DF is defined as carbohydrate polymers with 10 or more monomeric units which are not hydrolyzed by endogenous enzymes in the human small intestine. The dietary fiber is classified as total, insoluble and soluble dietary fiber. The dietary fiber can be supplied by a normal food intake (diets with high content of fiber) or as an ingredient added to food products generated previously by different processes (enzymatic, physical or chemical) from a great variety of raw materials (Guevara-Arauz et al. 2011). Moreover DF is one of the food components approved for use in functional foods throughout the world since it contributes to colonic and coronary artery health.

The aim of this study was to produce *nopal*-based bread rolls and evaluate the effect of the different *nopal* dietary fiber fractions on rheological and morphological properties of dough as well as quality, sensorial, physical and mechanical characteristics of the developed baked bread crumb rolls.

Materials and methods

Raw material (*Opuntia ficus-indica* plants, cv. Milpa Alta) was obtained from a pilot plantation in the Agronomy School of Autonomous University of San Luis Potosí, México. The prickly pear cactus stems (about 15–20 cm long and respiration rate of 11.2 $\mu\text{l/kg s}$) were manually harvested (a day before being processed) by cutting the articulation with the ‘mother cladode’ during afternoon. The cut zones were immersed in a solution of ascorbic acid (100 ppm) for 15 min. Stems were placed in covered containers and taken to the laboratory. They were washed in a NaOCl solution (200 ppm) at 4 °C for 15 min and quickly dried using a fan. Furthermore they were selected and classified according to size, uniformity and freedom of defects. The respiration rate of the stems was determined using a closed system adapted to cladodes by Guevara et al. (2006). All reagents were purchased from Sigma-Aldrich, Mexico.

Nopal dietary fiber fractions

The different fractions of prickly pear cactus dietary fiber (TF, IF and SF) were obtained according to AOAC official method 991.43. Each one of fractions were freeze-dried using a freeze dryer (Labconco, Kansas City, MO, USA).

Chemical analysis of nopal and wheat flour

The following AOAC official methods were used to characterize the raw materials: moisture: 934.01, nitrogen: 2001.11, fat: 920.39, ash: 942.05 and dietary fiber (total, soluble and insoluble): 991.43 (AOAC 2000). The analyses were done in triplicate.

Bread roll formulations

Four types of bread rolls were produced according to the proportion of ingredients described in Table 1. Wet ingredients were mixed and then poured onto pre-mixed dry ingredients. The resultant mixture was mixed thoroughly (Mixer SZM-20, Guangzhou XuZhong Food Machinery Co. LTD, Guangzhou, China) and rolled by hand. Subsequently, 95 g were weighed out, put on a tray and rested for 15 min. The dough were proofed using a proofing cabinet (C535-CFC-L, InterMetro Industries Corp., Wilkes-Barre, PA, USA) at 37 °C for 45 min and immediately baked at 180 °C for 20 min using a TEDESCO oven (FTT 300, Coaxias do Sul/RS Brasil). The rolls, whose final weight was 80 g approximately, were packed in polyethylene bags of high density and stored for 2 days at room temperature.

Dough analysis

Rheological assays

To formulate the different dough, it was employed the same process and quantities described in the previous section with the only modification that cold water (4 °C) was used to stop yeast activity. Dough was covered with a plastic film to avoid dehydration and left to rest for 15 min at 4 °C. Dough from each treatment were prepared in triplicate, laminated and cut in cylindrical pieces of 0.02 m in diameter and 0.05 m in height. Dynamic oscillatory tests were performed on a controlled stress oscillatory rheometer (Rheoplus, AntonPaar, Germany) using a serrated plate-plate sensor system with a 0.0015 m gap between plates. The samples were placed onto the base plate and the upper plate was brought to a gap of

Table 1 Bread roll formulations added with *nopal* dietary fiber

Ingredients	Treatments			
	Control	Total fiber	Insoluble fiber	Soluble fiber
Wheat flour (g)	100	100	100	100
Distilled water (%*)	38	38	38	38
Salt (%*)	1.6	1.6	1.6	1.6
Yeast (%*)	1.07	1.07	1.07	1.07
Sucrose (%*)	3.0	3.0	3.0	3.0
Vegetal oil (%*)	0.95	0.95	0.95	0.95
Improver (%*)	0.95	0.95	0.95	0.95
Total fiber (%*)	-	3.6	-	-
Insoluble fiber (%*)	-	-	2.18	-
Soluble fiber (%*)	-	-	-	0.36

* With respect to the quantity of wheat flour

- No added

0.001 m where excess material was carefully trimmed off. To prevent sample dehydration during the assay, mineral oil was applied. Before measurements, samples were allowed to rest 10 min at 25 °C between plates to relax residual stress. Storage modulus (G'), loss modulus (G''), complex modulus (G^*) and $\tan \delta$ were calculated using the manufacturer's software. The linear viscoelastic range and the target strain were determined using amplitude sweeps applying strain (γ) increasing from 0.001 to 100 % at a constant frequency (ω) of 1 Hz. Frequency sweep tests were performed at frequencies between 0.1 and 50 Hz with a target strain of 10^{-4} (0.01 %) at a constant stress (5 Pa) within the linear viscoelastic range. The results are the average of nine determinations per treatment.

Polarized light microscopy

The morphology of the starch granules was visualized and recorded with a polarized light microscope (Motic BA300, Motic Incorporation Ltd, China) fitted with a digital camera Moticam 2500 (Motic Incorporation Ltd, China). Fresh dough samples (1 g) were placed on a standard glass microscope slide and carefully covered with cover slip. Samples were allowed to rest for 5 min before visual analysis. Visual magnifications were $40\times$.

Bread roll analysis

Crumb texture analysis

Samples (cut by an electronic knife) of 0.04 m thickness $\times$ 0.03 m length $\times$ 0.03 m wide obtained from the roll center part were assessed applying 'texture profile analysis' double compression test (TPA) using a texture analyzer (TA.XT.Plus, Texture Technologies Corp, NY) equipped with a 25 kg load cell and a 0.1 m aluminum cylindrical probe. The settings used were a force of 0.98 N to compress 50 % of its original height and a test speed of 1 mm/s with 15 s delay between the 1st and 2nd compression (Ellouze-Ghorbel et al. 2010). Primary (hardness, cohesiveness and springiness) as well as secondary mechanical parameters (adhesiveness and chewiness) were calculated from the TPA curves using the TPA software (4.0.13.0 Exponent stable Micro Systems). Values reported are the mean and standard deviation of ten different determinations. On fresh rolls, crumb texture analyses were performed after cooling for 1 h at room temperature.

Roll specific volume and density determination

After cooling, the roll specific volume was determined by rapeseed displacement and weighted 1 h after baking so it corresponds to the quotient of bread volume (m^3)/roll weight (kg). The density was determined as the inverse of the specific

volume. Improvement of roll specific volume was calculated as follow:

$$I(\%) = [(sv_{\text{test}}/sv_{\text{control}})-1] \times 100$$

Where I is improvement and sv is the specific volume. Ten samples for each treatment were analyzed and results were expressed as mean values and their corresponding standard deviations.

Rate of staling

The aging of bread was assessed by determining the crumb hardness trying to replicate the normal conditions of marketing. Ten loaves per treatment were analyzed at 0 and 2 days of storage at room condition. Rate of staling (RS) was calculated using the following equation:

$$RS = (\text{crumb hardness day 2} - \text{crumb hardness day 0}) / \text{crumb hardness day 0}$$

Sensory analysis

One hour after baking, the different roll formulations were analyzed by 21 panelists according to the ISO standard (6658:2005 E) as a general guidance for sensory assessment in a sensory panel room at 25 ± 2 °C over one session. Panelists were asked to assess the rolls for the following acceptability parameters: surface characteristics, crust color, crumb color, texture, taste, mouth feel, and to mark on a 10 cm line (0=unacceptable, 10=very acceptable) in accordance with their opinion. The overall quality score (60) is the combined score of all these parameters (Nandeesh et al. 2011).

Statistical analysis

The data were statistically analyzed using analysis of variance (ANOVA) to study effects and Student's t -test to differentiate means at 95 % confidence level. The software used was the XLSTAT (Addinsoft, New York, N.Y. USA).

Results and discussion

Prickly pear cactus composition

The chemical composition of *nopal* was proteins (4.49 %), lipids (1.1 %) and ash (19.9 %), agreed with those reported previously by Sáenz (2006), whose reported respective values of 5.4 %, 1.29 % and 18.2 % corresponded to one year bud stems. The moisture level of *nopal* (93.45 %) was within the range (85–95 %) previously reported by Stintzing and Carle

(2005). The TF (31.44 %), SF (20.96 %) and IF (10.48 %) contents in *nopals* were lower than those 42.99, 28.4 and 14.54 % for TF, IF and SF respectively, reported by Sáenz et al. (2010) on cladodes flour with a moisture content of 7.14 %. Previously Ayadi et al. (2009) found TF levels of 41.8 % for dried cladodes without thorns. The highest contents of TF (56.56 %), IF (41.65 %) and SF (14.91 %) in cladodes (var. redonda, 7.31 % humidity) cut 65 days after budding were reported by Rodríguez-García et al. (2007). This discrepancy might be due to different variety, crop climatic conditions and mature index studied in the different works. In general the dietary fiber content determined in cladodes is higher than the content found in whole wheat flour (12.57 %) and wheat flour (2.78 %). When a crop shows an IF/SF ratio closer to 2 it could be considered as an adequate source of fiber (Jaime et al. 2002). Although the IF/SF ratio obtained in this study was somewhat similar to that reported by Saenz et al. (2010) for dried cladodes, this value was lower than that reported by Rodríguez-García et al. (2007) and Ayadi et al. (2009), whose reported IF/SF ratios were 2.8 and 3 respectively.

Rheological assays

The storage modulus of a material refers to the deformation energy stored in the material after oscillation is removed. It is a

measurement of a material's elastic properties. The higher the value is, the more elastic the material will be. The loss modulus of a material refers to the energy lost from the sample during oscillation. If energy is lost, the sample cannot go back to its original shape, which is an indication of viscous behavior.

The typical amplitude sweep obtained for roll dough by rheometric assays showed that all dough had a higher storage modulus (G') than loss modulus (G'') indicating that dough presented an expected solid, elastic-like behavior (data not show). Before proofing, G' , G'' and G^* modulus values did not show significantly difference among treatments (Fig. 1). TF-dough showed a significantly higher value of $\tan \delta$ which means that TF-dough is softer, less adhesive, more cohesive and with a less elastic behavior (i.e. more viscous) than the other treatments, characteristics that are lost after proofing. After proofing, IF-dough had the most visco-elastic behavior, while SF-dough showed the lowest values in all modulus (G' , G'' , G^* and $\tan \delta$), indicating that this sample had the less visco-elastic (softer) behavior (Fig. 1). These results agree well with the observed mechanical properties of softest, but resilient, SF-crumb indicating a straight relation between dough rheological and crumb mechanical properties. The differences between adding or not adding fiber to dough could be attributed to differences in the interaction of starch-gluten

Fig. 1 Rheological behavior of doughs enhanced with different fiber fractions of *nopal* before and after proofing. C control, TF Total fiber, IF Insoluble fiber, SF Soluble fiber, ($n=9$)

in composite dough. It is likely that high values of G^* , G' and G'' modulus obtained for the IF treatment, after proofing, were due to the presence of interactions between cellulose, hemicelluloses and lignin with the gluten matrix into dough through hydrogen bounds, enhancing its increased structural strength. This indicates that the addition of IF to dough increases its resistance to deformation, resulting in a firmer product after proofing. On the other hand, the changes in the SF-dough rheology might be due to mucilage and pectin presence, which have higher affinity for water uptake. Although both, mucilage and pectin present in *nopal* soluble fiber can establish hydrogen bonds with starch through hydroxyl groups, low methoxyl pectin LMP (DE=43 %) would be more able than mucilage to establish, additionally, hydrophobic unions with proteins, a type of interaction particularly

favored by the presence of NaCl. This could explain the lower G^* , G' , G'' and $\tan \delta$ values for SF treatment compared with the control experiment after proofing.

Polarized light microscopy

Changes in the internal structure of the starch granule, as a function of fiber fraction added, were observed using polarized light microscopy (PLM). On Fig. 2, it can be observed that the addition of SF (micrographics XIII - XVI) developed a better and a suitable distribution of starch granules which showed birefringent behavior. This might be explained in terms of the interaction between SF and gluten-starch matrix. This is in agreement with the findings of other researchers (Mamat et al. 2010; Aibara et al. 2005), who showed an initial

Fig. 2 Light-polarized microscopies of dough samples captured under bright field (odd numbers) and dark field (even numbers). Control (I–IV), TF (V–VIII), IF (IX–XII) and SF (XIII–XVI), before proofing (I, II, V,

VI, IX, X, XIII, XIV) and after proofing (III, IV, VII, VIII, XI, XII, XV, XVI). Magnification was 40×

extensive formation of coarse protein filaments surrounded by starch rich domains. The images for the control experiment and the TF-added sample showed discontinuous starch rich domains demonstrating structural heterogeneity in the dough. Unlike SF, the addition of IF to dough improved the conglomeration of starch granules as a result of a minimum interaction of its components (cellulose and hemicelluloses) with the starch.

Crumb texture evaluation

Textural attributes of bread rolls formulated with *nopal* dietary fiber are shown in Fig. 3. For fresh rolls (day 0), the addition of TF, IF and SF fiber decreased the hardness of bread rolls developed. Although the SF-roll hardness increased after 2 days of storage from 3.25 to 4.78 N, this value was different ($p < 0.05$) compared with the rest of treatments. The low values found in these samples are desirable, since consumers relate a firm crumb to an old product. Crumb cohesion is a desirable property in breads. By measuring crumb cohesiveness one can understand the degree of sample integrity when it is deformed. Although the inclusion of TF (0.31), IF (0.24) and SF (0.29) to roll formulation led to a significant decrease ($p < 0.05$) in crumb cohesiveness compared with control experiment (0.35), after 2 days of storage SF-roll cohesiveness (0.261) could be considered constant (Fig. 3). These results suggest that rolls formulated with *nopal* fiber had a less

integrated matrix. However, SF-rolls integrity was kept throughout the storage. This agrees with the study of Gujral et al. (2003), who reported that the addition of barley flour to a wheat bread formulation caused a decrease in crumb cohesiveness. Crumb springiness, a value describing the recovery of the sample after compression, is important in separating soft, soggy crumb from soft but resilient crumb. In comparison with control, springiness values for TF, IF and SF treatments were constant throughout storage, indicating that the addition of *nopal* fiber to the recipe did not show a significant effect on this attribute (Fig. 3). Chewiness, the product of hardness, cohesiveness and springiness, gives an indication of the energy required to masticate a solid food. After 2 days of storage, the SF treatment showed the lowest chewiness value (0.806 N) which was statistically significant (Fig. 3). Overall the SF-rolls were softer and showed resilient crumbiness, as well as excellent recovery properties.

Roll specific volume and density

An important property, known to influence consumer's choice strongly, is the roll-specific volume. From an economic standpoint, a high ratio of volume per weight is desirable. Due to the exceptional viscoelastic properties of gluten, gas retention during proofing and baking is higher in wheat dough. Therefore, loaf-specific volume of wheat-roll could be considered high ($2.4 \times 10^{-3} \text{ m}^3/\text{kg}$, Table 2). TF addition did not show

Fig 3 Texture profile analysis of crumb throughout 2 days of storage. TF Total fiber, IF Insoluble fiber, SF Soluble fiber, ($n=10$)

Table 2 Effect of nopal fiber addition on specific volume, density and sensory characteristics of bread rolls

Roll	Specific volume $\times 10^{-3}$ (m^3/kg)	Density $\times 10^{-3}$ (kg/m^3)	Rate of staling	Sensory characteristics of rolls*						
				Surface characteristics	Crust Color	Crumb color	Taste	Mouth feel	Texture	Overall quality
Control	2.48 ^a $\pm$ 0.378	0.41 ^a $\pm$ 0.068	0.458 ^a $\pm$ 0.066	8.3 ^a	8.2 ^a	8.4 ^a	8.2 ^a	8.0 ^a	8.4 ^a	49.7 ^a
TF	2.70 ^b $\pm$ 0.020	0.40 ^a $\pm$ 0.032	0.296 ^b $\pm$ 0.059	6.7 ^b	7.7 ^b	7.6 ^b	7.5 ^b	6.8 ^b	7.9 ^b	44.2 ^b
IF	2.51 ^a $\pm$ 0.208	0.37 ^b $\pm$ 0.003	0.381 ^c $\pm$ 0.094	7.6 ^c	7.2 ^b	7.3 ^b	7.8 ^b	7.8 ^c	7.6 ^b	44.4 ^b
SF	2.79 ^c $\pm$ 0.161	0.36 ^b $\pm$ 0.020	0.199 ^d $\pm$ 0.081	9.1 ^d	8.9 ^c	9.8 ^c	9.7 ^c	9.5 ^d	9.6 ^c	56.6 ^c

Data are presented as mean $\pm$ standard deviation for specific volume and density ($n=10$)

^{a-d} Values in the same row without similar letter differ significantly at $p \leq 0.05$ by using Student's *t*-test comparison

*Standard deviation is not show ($n=21$)

effect on roll specific volume ($2.51 \times 10^{-3} \text{ m}^3/\text{kg}$), whereas SF treatment showed the best improvement on roll specific volume (12.46 %). Hence SF treatment showed lower density values. It is likely that mucilage and pectin present in SF-enriched treatment can improve dough development and gas retention by decreasing dough viscosity (Lazaridou et al. 2007). Similar results were found by Bahareh et al. (2013) who reported that the specific volume and porosity of bread increased with the addition of hydrocolloids alone or in combination.

Rate of staling

The shelf life of any bread is determined by the staling behavior of the product and/or its microbial deterioration. SF and TF-rolls staling rate were significantly lower (0.199 and 0.296 respectively) compared with control treatment (Table 2). This was expected since mucilage and pectin present in SF have a considerable tendency to interact with water (Correa et al. 2011). Bread staling involves crumb firming, which has been attributed mainly to recrystallization of amylopectin and water redistribution between crumb and crust. The changes in staling rate are in large part attributable to the retrogradation behavior of starch and hence the ratio of amylose to

amylopectin (Singh et al. 2003). It is also important not to discard the possible interaction between the soluble components of the fiber (mucilage and pectin) with gluten and starch. Sciarini et al. (2010) previously proposed that in wheat breads, the gluten network slows down the movement of water; thus, gluten-free breads are more prone to stale. Nonetheless, it has been shown that other factors different from the presence or absence of gluten influence the staling rate (Hager et al. 2012).

Sensory analysis

The data on sensory characteristics of rolls showed that addition of TF and IF reduced the sensory scores of rolls significantly (Table 2). The rolls prepared with TF had the lowest score (44.2) while the addition of IF to rolls resulted in a darker crust and greener crumb coloration (score 44.4) so that they were less acceptable (Fig. 4). Sudha et al. (2007) and Shimray et al. (2012) reported similar observations in their evaluation on sensory characteristics of biscuits added with rice bran and finger millet powder, respectively. When SF was added to rolls, a significant improvement in all sensory characteristics was computed (56.6) compared with the control (49.7). The scores for crust and crumb coloration did not change significantly with the addition of SF fraction. This

Fig. 4 Rolls picture. **a** Control and rolls added with: **b** Total fiber, **c** Insoluble fiber, **d** Soluble fiber

may be due to the lack of chlorophyll in the soluble fiber fraction which was added to the formulation.

Conclusions

The addition of soluble fiber produced the softest dough therefore; a less visco-elastic behavior was obtained and a better distribution of starch granules was developed into SF-dough. These results agreed with crumb texture profile analysis where the lowest hardness and chewiness were showed by SF-roll crumb. In addition, rolls formulated with SF showed the lowest rate of staling, had excellent bread acceptability and showed an increase in specific volume. On the other hand, the addition of total fiber and insoluble fiber developed harder dough than the control experiment accordingly; higher crumb hardness and chewiness were showed by these treatments. These improvements on rolls may be considered additional to the nutritional benefits of *nopal* soluble fiber which has been shown. It has prebiotic activity so further studies should be addressed in order to determine the possible biofunctionality of these rolls.

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