Full Length Research Paper

Functional Properties of a High Fiber and Protein Snack Made with Blue Corn and Legumes added with Natural Antioxidants

1Y. Ramos-Barrera, 2Y. Rivera-Espinoza, 1F. García-Ochoa, 3M.P. Salgado-Cruz, 2aO.A. Ramos-Monroy, 1P. Rosales-Martínez, 1M.T. Hernández-Botello, 1M.S. López-Cortez*

2Departamento de Ingeniería Bioquímica.

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The consumption of snacks has modified the conventions around how people eat. The "snackification" (increasing consumption of snacks in replacement of meals) of our eating habits is driving the growth of the snack sector. The new demands for consumption and growth in the sector have generated the need to develop snacks with functional components to obtain healthier products. The use of legume flours is becoming a global trend in all sectors and today the legumes take over the snack category. Considering the high protein content of some legumes such as beans, chickpeas and peas, and the high antioxidant content in tomato processing residues, in the present study, a baked "chips" snack was developed, using blue corn, beans, chickpeas, peas and tomato skin powder and seeds, to obtain a high concentration of protein, fiber and antioxidants. Snacks were developed using grains both independently and in mixtures, with the highest protein concentration attributed to pea mass (20.7%). The snacks prepared with the mix presented an increased protein and fiber content compared to those prepared with blue corn. The addition of tomato powder increased the antioxidant capacity from 0.102 ± 0.003 to 474.46 ± 0.133 mmol TE/100 g and improved the sensory characteristics. The snack with the highest concentration of antioxidants was made with a proportional mixture of corn, beans, chickpeas and peas with added tomato powder.

Keywords: Healthy snack, legums, blue corn

1. INTRODUCTION

In recent decades, the world have experienced a series of demographic, epidemiological, sociological and nutritional transformations.

Consumers now incorporate snacks constantly, blurring the line between what a snack is and what constitutes a meal. The current lifestyle, with less time to prepare meals, has put the snack many times in replacement of the food itself. A large number of English, American, Polish, French, Italian and Spanish consumers also often replace the main meals with snacks. The consumption of snacks is a growing market trend, with potato and corn chips being the most popular snacks worldwide (Kayacier et al., 2014). On
the other hand, the additives that are used in the preparation of snacks are those that favor organoleptic characteristics, such as texturizing agents (CMC gum, xanthan, locust bean, etc.), emulsifiers (lecithins), flavor enhancers (monosodium glutamate), dyes, flavorings and synthetic antioxidants; the latter with the only purpose of preserving food by inhibiting oxidation generated by lipids. Currently, it is preferred to incorporate these components from natural origins, for which other vegetables, such as legumes (which provide a higher protein content), have been added to corn-based snacks. However, although there is a wide variety of corn grains, blue corn has been used sparingly for the production of functional products. In a previous study, tortilla chips were made with mixtures of corn and beans, which increased the protein content, decreased the fat content (Figueroa-González et al., 2011). Lazou and Krokida (2011), obtained extruded corn flour and lentil mixtures and found that the lowest values of CHOS and lipids were in snacks made with 50% lentil flour. (Chávez-Santoscoy et al., 2016), added black bean shell extracts to the production of nixtamalized corn flour tortillas, which presented a flavonoid retention percentage of 79%.Dehghan et al.(2010), used tomato derivatives to improve the nutritional attributes of corn, rice and wheat snacks, adding lycopene and fiber. Based on the details above and because blue corn has a higher content of bioactive compounds than other corn varieties, along with the lack of reports of its use in snacks, this study proposes the development of a baked, blue corn-based chip with improved protein content from the addition of legumes and tomato antioxidants as a healthy snack option that provides protein, fiber, antioxidants and a low energy density. It is proposed to prepare the snack from the masses of the different grains to avoid processing stages used in obtaining flours, although the physicochemical and antioxidant properties of these flours were studied with comparative purposes; in addition tomato processing residues were used because it could represent an economic advantage in the preparation of healthy snacks.

2. METHODOLOGY

2.1 Raw materials: Five kilograms of each legume were used: pinto beans (Phaseolus vulgaris L.) were obtained from Sinaloa; chickpeas (Cicer arietinum L.) and yellow dried peas (Pisum sativum L.) were obtained from the stock market of Tultitlán, Mexico; and 5 kg of blue corn seeds were obtained from San Francisco Tejojacoín CuautitlánIzcalli, Mexico. For tomato powder preparation, 16.5 kg of Saladette tomatoes from San Luis Potosí, Mexico were used. All of the grains went through a selection and cleaning process to eliminate damaged grains, straw, impurities and/or other foreign materials (FAO 2016). Flour from each grain was made to characterize their physical and chemical properties.

2.2. Preparation of blue corn and legume flours. To prepare the flours, each grain underwent a different process due to their differing physical and chemical characteristics. A BINDER® E-series drying oven was used for the grain drying processes. In the case of the pinto beans, 1.5 kg of previously washed seeds were soaked in 4 L of H2O for 2 h at 95 °C; the seeds were then separated from the broth and left to drain for 2 h prior to their subsequent drying at 60 °C for 24 h in an oven (INIFAP 2010). Chickpea flour was prepared using 1.5 kg of seeds, which were washed and dried in an oven at 105 ± 0.1 °C for a period of 3 h (Fares and Menga 2012). For the pea flour, 1.5 kg of seeds were soaked for 30 min in 3 L of H2O at 50 °C to soften them; they were subsequently drained and placed in an oven for 2 h at 170 °C. The elaboration of the nixtamalized blue corn flour was carried out by placing 2 kg of seeds in 10 L of a solution of 1% calcium hydroxide (Ca(OH)2) in water at 95 °C for 45 min (Chávez-Santoscoy et al., 2016). The seeds were then left in their cooking water for 16 h at room temperature (Paredes et al., 2009), the soaking water was subsequently removed and the grains were rinsed with 10 L of drinking H2O until the excess Ca(OH)2 was eliminated. The cleaned seeds were drained for 2 h to remove excess water, and the grains were dried at 60 °C for 24 h in an oven.

Grinding of grains. The dried legume and corn grains were subjected to size reduction using a WOLFOX® brand manual grain mill (model WF2541) and sieved (ASTM (American Society for Testing and Materials)); the samples were agitation for 15 min, and the weight of the flour retained in each sieve was determined), obtaining an average diameter of 0.175 mm. According to (Serna 2013), the diameter obtained is considered a mass with coarse granulometry and is recommended for the preparation of snacks since a larger particle size favors increased pore quantities and the reduction of blisters in baked products, as well as lower oil absorption. For a control to evaluate the effect of temperature on the antioxidant capacity of the processed flours, 200 g of each of the clean raw grains were used, which were subjected to a size reduction in the same mill; these products were denoted as the corresponding grain powders (BCP, blue corn powder; BP, bean powder; CHPP, chickpea powder; and PP, pea powder).

2.2.1 Baking conditions of the chip-type snack. The evaluation of the baking conditions was carried out using a model snack made with 98 g of commercial blue corn flour, 2 g of NaCl and 100 ml of water at 95 °C (Xu and Kerr 2012). A factorial design, 23, with two central points was used to establish the baking conditions of the snack, where the three study factors were time, temperature and pretreatment with two work levels of 5 and 10 min, 275 and
Table 1. Design of mixtures of four factors for the preparation of baked snacks

<table>
<thead>
<tr>
<th>Std Order</th>
<th>Run Order</th>
<th>Pt Type</th>
<th>Blocks</th>
<th>% de MASSES OR FLOUR</th>
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<td>0.25 BCN 0.25 CHP 0.25</td>
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BCN: Blue Corn nixtamalized; CHP: Chickpea; B: Bens; P: Pea

325 °C and with and without previous cooking, respectively. The response variables of the model were antioxidant capacity and total phenols.

Preparation of the chip-type snack. The process diagram of (Kayacier et al., 2014), was used with some modifications that were made taking the operating conditions of the equipment as well as the use of the masses of each grain instead of flours to avoid the drying process. During lamination and molding, an average snack diameter of 5.53 ± 0.162 cm and a weight of 1.920 ± 0.213 grams were obtained.

2.3 Elaboration of masses of blue corn, beans, chickpeas and peas

2.3.1 Blue corn mass: was prepared by alkaline cooking; 2 kg of grains were weighed, placed in a solution of 10 L of 1% Ca(OH)₂ at 95 °C for 60 min, allowed to stand for 16 h in the cooking water, sieved to eliminate the nejayote and rinsed with 10 L of drinking H₂O until the excess Ca(OH)₂ was eliminated (Chávez-Santoscoy et al., 2016), the seeds and clean grains were drained for 2 h; the wet grains were ground in an aluminum manual mill (Estrella® model 11540).

2.3.2 Degree of cooking. To standardize the process, the degree of cooking of the blue corn grains was monitored. A 10 g sample was taken every 10 min to evaluate its fracture strength (N) and the rupture distance (mm). The data were obtained with an INSTRON® model 5565 universal texture testing machine using the compression program and a 500 N load cell, which was coupled to a 1.5 cm diameter cylinder, with a test speed of 10 mm/min (Ramírez-Jiménez et al., 2018). Texture measurements were made in triplicate for each sample.

2.3.3 Legume mass: One kilogram of grains was weighed and cooked in 10 L of drinking water at 95 °C. The cooking time and proportion of cooking water that was added to complete the process were determined by assessing the fracture strength (N) of the grains every 20 min. Then, the excess water was eliminated and the cooked grains were left to drain for 2 h, after which they were ground with the same mill used for the corn. The prepared masses presented a humidity percentage of 55 to 57%, which was within the values reported for fresh masses of nixtamalized corn (Flores-Farias et al., 2002).

2.4 Design of mixtures for the preparation of snacks. A design of simplex centroid mixtures of four factors was made in the MINITAB® 17 Software to establish the percentage of each of the masses used for the preparation of the snack. The design factors were the blue corn, bean, chickpea and pea masses with substitution levels of 0 to 100%, obtaining 19 mixtures for the formulation of the snack, which are presented in Table 1. The preparation of the snacks was conducted by placing 98 g of dough plus 2 g of salt in a pedestal blender (HAMILTON BEACH®, model 63932) at 200 rpm for 1 min; the dough was allowed to stand for 10 min in a plastic bag at room temperature, then the mixture was rolled to a thickness of 1 mm and a
diameter of 5.53 ± 0.162 cm in a manual laminator (IBIL®
model SP24) and was molded and baked at 325 °C for 10
min in an electric oven (HAMILTON BEACH®, model
31105).

2.4.1 Adding tomato powder. The tomato powder was
prepared, obtaining a powder of an average particle size of
0.5075 mm, a humidity percentage of 7.8 ± 0.236% and an
apparent density of 0.57 ± 0.01 g/mL. Before the addition
of tomato powder, the 5 snacks that presented the best
sensory characteristics were selected. The snacks with
added tomato powder were made using 92 g of the mass
mixture, 2 g of salt and 6 g of tomato powder. Six percent
tomato powder was used because this percentage
represents the total weight of the skin and seeds of the fruit
(Toor and Savage 2005), and favors the retention of
compounds when subjecting the product to thermal
processes (Dehghan et al., 2010).

2.5 METHODS OF ANALYSIS

2.5.1 Chemical composition of the flour: The chemical
composition of the flour was determined according to the
methods reported by the A.O.A.C and Official Mexican
Norms (NMXs): Humidity (AOAC 2011), using an Ohaus
scale, model Analytical Plus AP 110; Ashes, General
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model SP24) and was molded and baked at 325 °C for 10
min in an electric oven (HAMILTON BEACH®, model
31105).

2.5.1.2 Physical-chemical parameters of the flours: The
water absorption index (WAI), water solubility (WS) and
hydration capacity (HC) were determined by the
methodologies established by Flores-Farias et al.,[13] with
some modifications and evaluated at three temperatures
(30, 60, and 80 °C). A 0.5 g sample of flour was weighed in
previously diluted 15 mL propylene tubes, to which 6 mL of
distilled water was added and placed in a water bath,
stirring at the test temperature for 30 min; the samples
were subsequently centrifuged (UNICO® model c8724) at
4500 rpm for 25 min. The supernatant was decanted and
then dried at 90 °C in aluminum trays of a known weight in
an oven to obtain a constant weight (dry supernatant). The
flour retained in the tubes was weighed (gel). Subsequent
calculations were made according to Equations 3 a, b and
c.
a) WAI=(WG)/M; b) % WS=(Wds )/W; c) % HC=PG/(M-
PSs) Ecs. (3)
Where W = Sample weight [g]; Wds = Weight of the dry
supernatant [g]; WG = weight of the gel [g].

2.5.2 In vitro digestibility of protein: The in vitro
digestibility of protein was determined by the methods
modified by (McDonough et al., 1990), using the Equation
2, which was obtained with reference to a Hammarstein
casein solution, where x is the pH obtained after 10 min.

% Protein Digestibility = 210.46-18.19 x
(2)

2.5.3 Microbiological Analysis. The determination of
the hygienic quality of the flours was carried out according
to the official Mexican standard of products and services
for cereals and their products (NMX-F-089-S-1978), which
requires the determination of aerobic mesophiles, total
coliforms, molds and yeasts.

2.5.4 Determination of bioactive compounds

Antioxidant extract: A sample of 5 g of each grain was
added to 10 mL of 80% methanol, and the solutions were
maintained for 2.5 h at 70 °C while stirring at 200 rpm. The
extracts were centrifuged at 4500 rpm for 20 min, decanted
and filtered; the supernatant was used to determine the
antioxidant capacity and the phenolic content.

Total phenolic compounds (TPC). This determination
was carried out according to the methodology established
by (Singleton et al., 1999), with some modifications, using
reagent of Folin-Ciocalteu and a spectrophotometer
(BIOMEDICAL® model SPV100). A standard curve of
gallic acid was prepared to express the results as mg of
gallic acid / g of sample (y = 0.0029x + 0.093, R²= 0.9963).

Antioxidant capacity by DPPH: The determination of
antioxidant capacity was carried out using the DPPH
radical, where the percentage of inhibition was calculated
according to Equation 3.

% inhibition = 100
Ablank
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% inhibition = 100
A blank
A

Where A is the absorbance read. The percentage of
inhibition obtained from the sample was interpolated in the
standard curve of Trolox at concentrations of 100 and 1400
µmol (y = 0.0528x + 9.9892, R²= 0.999). The percentage of
inhibition obtained from the sample was interpolated in the
Trolox standard curves at concentrations of 100 and 1400
µmol.

Antioxidant capacity by ABTS⁺ (Hayta and İşçimen
2017). A sample of 30 µL was mixed with 3 mL of the
radical that was diluted in ethanol for 6 min. Afterward,
absorbance was read at 734 nm, and the result obtained
was used in Equation 4 to calculate the percentage of
inhibition by ABTS. This parameter was interpolated using a
Trolox standard curve.

% inhibition = 100
A blank
A

Where A is the absorbance read. The percentage of
inhibition obtained from the sample was interpolated in the
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inhibition obtained from the sample was interpolated in the
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2.5.6 Sensory evaluation. The sensory characteristics
of the snacks were evaluated by 5 judges trained with a
preference test that was set at intervals. Judges scored
sensory characteristics on a scale of 0 to 5, where 0 was
not at all pleasant and 5 was very pleasant; tests for
appearance, taste and texture (crunch / consistency) were
conducted. The snacks with added tomato powder were evaluated by 10 untrained judges using an acceptance test qualifying the attributes of taste, color, appearance, and texture (Tomić et al., 2016).

2.5.7 Statistical analysis. The statistical analysis was carried out using MINITAB® 17 Software; the results were analyzed using a one-way analysis of variance (ANOVA) and a Tukey comparison test with an α of 0.05 to determine the factors that had a significant effect.

3. RESULTS AND DISCUSSION

3.1 Proximate chemical analysis of legume and blue corn flours. Table 2A shows the results obtained in the proximal chemical analysis for blue corn (BCNF), commercial corn (CoCF), beans (BF), pea (PF) and chickpea (CHPF) flours. The moisture values of the BCP (blue corn powder) and the BCNF (blue corn nixtamalized) presented significant differences (p < 0.05), while the BCNF and the CoCF did not. These values are similar to those reported by (Camelo-Méndez et al., 2017). (9.8 ± 0.1%).

The humidity of the corn flour obtained for the BCN was within the range established by (NMX-F-089-S-1978), for corn flour.

The protein values obtained for the BCP and the BCNF were significantly different (p < 0.05), with higher BCP values than the BCNF. The amount of fat in the BCP and BCNF samples did not present a significant difference (p > 0.05), but the CoCF values were significantly lower than the 5.2% reported by (Camelo-Méndez et al., 2017), for blue corn flour. The amount of fat in the grains can vary depending on the species of corn (Somavat et al., 2016). The percentage of carbohydrates (CHOS), for the BCP and the BCNF were significantly different (p < 0.05), with higher values for BCNF, which could be due to the nixtamalization process. During this operation, starch retrogrades due to the time it remains at rest in the cooking water (Paredes et al., 2009). The ash value was higher in the BCNF compared to the BCP, and this variation was directly attributed to the concentration of calcium added for

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nixtamalization, the cooking temperature, the soaking time and the level of lime removed when washing the cooked grain (Camelo-Méndez et al., 2017). Fiber content was not determined, but it has been reported that tortillas and other products (snacks, toasts and tamales) made with nixtamalized blue corn flour generally have a higher dietary fiber content, such as those obtained in this work for legumes (Table 2A). (Bello et al., 2015). reported a value of 14.11±1.42 g/100 g of fiber for blue corn flours.

In the legumes, Table 2A, the BF presented higher humidity value that is mainly due to the elaboration process since the parameter presents a direct relation between the times for soaking and cooking the grains. The humidity of the CHPF was lower than the reported by Du et al., 2014. (11.2%). The low moisture content of flours is mainly due to the temperatures used during drying. The humidity of the BP was found within the range obtained by Ma et al., 2017, who reported 0.88% for toasted pea flour and 8.71% for raw pea flour. The humidity values of the BF, CHPF and PF comply with the values specified in (NMX-F-089-S-1978). Regarding protein content, the BF presented a significantly different value (p <0.05) compared to the CHPF and PF. The protein percentage of the CHPF was lower than that reported by (Du et al., 2014), who reported values higher than 22% protein for chickpeas of Canadian origin. The percentage of protein in the BF was lower than the value reported by Ma et al., 2017, 20.26% for cooked yellow pea flour; according to the author, the reduction in the protein content of the flours is due to the effect of the temperature used for its elaboration. Since the legume grains are susceptible to the formation of volatile compounds containing nitrogen during roasting, leading to a significant reduction in the total crude protein content (Ma et al., 2017). The BF had a protein content of 25.36%, which is higher than the 18.8% value reported by Aguilera (2010). This difference is because the protein content of the different legumes depend on factors such as the seed variety, the application of fertilizers, the location of the crop and the environmental conditions (Du et al., 2014). The fat contents of the PF and CHPF was similar to that reported by Du et al., 2014, being of 1.5% for the pea sample while for the chickpea of 6.63% and for the BF, the fat value was higher than the 1.51% reported by the same author. The values obtained from carbohydrates (CHOS) for legume flours are similar to those reported in the literature (69.6 to 79.9 g/100 g of flour) (Aguilera 2010). The carbohydrates present in legumes are mainly made up of starch, dietary fiber and soluble sugars. Ash values ranged from 1.33 to 3.53% and the variation values is due to the leaching process that occurs during soaking, cooking and dehydration (Aguilera 2010).

3.2 Protein digestibility. The value obtained from the in vitro digestibility of the BCP protein was 71.99 ± 0.77% and that of the BCNF was 74.438 ± 0.384% with a significant difference (p <0.05). The increase in protein digestibility is mainly due to the denaturation that these components undergo due to the temperature of the flour production process and the reduction or elimination of different antinutritional components (Gilani et al., 2012). In legumes, the highest percentage of in vitro protein digestibility was obtained in the PF (80.23%), followed by the CHPF (77.51%) then by the BF (76.15%); each value was within the reported range for legumes, which is from 83.99 to 92.45 % (Ma et al., 2017). The CHPF presented a digestibility of 77.51%, which was found within the range of 76 to 78% reported by González et al., 2006. This difference is because of the seed variety.

3.3 Physicochemical analysis and functional properties of the flours.

3.3.1 pH. The alkalization process increased the pH of the unprocessed corn (BCP) to 5.95 and 8.93 for the BCNF. During alkaline cooking, the grains absorb Ca(OH)_2, which favors the dissolution and swelling of the pericarp layers. The pH values for the powders of the unprocessed grains and legume flours varied between 6.32 (CHPF) and 6.66 (BF); these values are similar to those reported by Aguilera (2010), who stated that the pH increased when the seeds were subjected to the same process and the differences between samples could be attributed to the legume variety. The determination of pH the flours is important since it affects some technical-functional properties, which are mainly related to proteins.

3.3.2 Functional properties of the flours, WAI, WSI and HC: The average values of the water absorption index (WAI), the water solubility index (WSI) and the hydration capacity (HC) of the flours at 30, 60 and 80 °C are presented in Figure 1, which shows significant differences (p <0.05) at the different temperatures. The highest values for WAI and HC were at 80 °C, while the WSI value was lower at 80 °C for the CoCF, CHPF and BF.

Hydration capacity: The CoCF presented an HC at 80 °C of 5.117 g/g, which is higher than that obtained for the BCP and the BCNF. There is a direct relationship between the HC and the ratio of amylose amylopectin of the starches and the cooking temperature. Agama et al., 2017 reported that white corn contained a starch percentage of 76.22%, consisting of 20.59% amylose and 79.41% amylopectin, unlike blue corn, which has a starch percentage is 66.54%, of which 22.35% is amylose and 77.65% is amylopectin (20). The HC for the CHPF at 80 °C was 4.22 g/g, and is within the range of 2.5 to 5 g/g of the HC for the Spanish chickpea. The results of Aguilera (2017) show HC intervals for flours of fresh and processed legumes ranging from 1 g/g to 5.1 g/g.
Water absorption index: For the BCP and the BCNF at 80 °C, the values obtained were 4.109±0.09 g/g and 3.548±0.03 g/g, respectively, and were similar to that reported by Flores-Farias et al., [13] who obtained 3.6 ± 0.2 g/g for a white corn flour. The WAI of the CHPF was found in a range of 3,099 to 4,550 g/g, which was lower than the values obtained by Bouasla et al., [30] with 6.13 g/g. On the other hand, it was observed that the flours had a higher WAI at higher temperatures, which can be attributed to the starch gelatinization process, which starts at 60 to 70 °C. The WAI indicates the volume occupied by the starches after they swell from the excess water; therefore, the differences in WAI can be attributed to the proportions and compositions of the starches that the different grains contain [24].

Water solubility index: The data obtained showed a significant difference (p <0.05) between the types of flour, with the highest WSI being that of the PF (18.749%) and the lowest of the CoCF (0.165%). During the water absorption process, the solubility of some molecules, mainly amylose, is favored; amylose diffuses into the water and, if the heating continues, breaks down and partial solubilization is observed. The main source of variation of the functional characteristics of the flours is the composition and conformation of the starches present in each legume and cereal.

Knowledge of these properties is important to consider when using these flours for processes such as baking, cooking, etc.

3.4 Microbiological characterization. Chickpea flour was the only flour that presented a microbiological load, with 7 CFU / g of aerobic mesophiles and the total absence of coliforms, molds and yeasts; bean and pea flour were devoid of microorganisms. An absence or low concentration of microorganisms is mainly due to the temperature used in the process of making the flours. For corn powder and nixtamalized blue corn flour, 250 and 10 CFU/g of molds and yeasts were obtained, concentration lower than the allowed 1000 CFU/g by (NMX-F-089-S-1978). Blue nixtamalized corn flour and legume flour both complied with the specifications established by the standard.

3.5 Conditions for the preparation of the snack. There were no significant differences (p >0.05) for the parameters evaluated in the factorial design carried out with the MINITAB® 17 software. Therefore, the analysis of each response was performed with respect to the process conditions. The best baking conditions for obtaining the maximum values for total phenols and antioxidant capacity were 325 °C for 10 min, without precooking. These results were adjusted to the temperature and time interval established by (Singh et al., 2009), and under these conditions.
conditions, the snack obtained presented a weight of 1.48 g and a diameter of 5.6 cm (values were within the average range obtained for the laminate).

3.5.1 Establishment of the process conditions for the preparation of the snack

There were no significant differences (p >0.05) for the parameters evaluated in the factorial design carried out with the MINITAB® 17 software, which were as follows: the antioxidant capacity by DPPH and ABTS, the total phenols and the average diameter and weight, each with respect to the factors (time, temperature and precooking) (Figure 2). Therefore, the analysis of each response was performed with respect to the process conditions. The best baking conditions for obtaining the maximum values for total phenols and antioxidant capacity were 325 °C for 10 min, without precooking. These results were adjusted to the temperature and time interval established by Singh et al., [31], and under these conditions, the snack obtained presented a weight of 1.48 g and a diameter of 5.6 cm (values were within the average range obtained for the laminate).

3.6 Cooking time of the grains to elaborate the masses: The fracture force in Newtons (N) was determined both as a texture parameter and as a function of the cooking time to determine whether each corn and legume grain has an adequate texture to prepare the dough. The results obtained are presented in Figure 3.

The crude blue corn BCP presented a fracture force of 281.02 ± 0.301 N, which was reduced to 30.49 N when the grain was subjected to nixtamalization for 60 min (Figure 3a). According to (Chávez-Santoscoy et al., 2016), the optimal time for the nixtamalization process is 40 min, in which the action of the OH- radicals deteriorates part of the pericarp of the grain, facilitating the absorption of water by the endosperm and generating a partial, 15%, gelatinization in the starch granules.
For crude legumes, the fracture force was in an interval of 279.87 to 503.14 N, with chickpea showing the highest level. In the cooked legumes (Figure 3), the fracture strength after 60 min did not present a significant difference \((p > 0.05)\), and the final values were in the range of 2.95 to 6.63 N, similar to the values reported by (Aguirre-Santos et al., 2011). The higher fracture strength values in the grains are directly related to the storage time of the grain and its capacity to absorb water. As seen in Figure 3, after 60 min, there was no significant difference \((p > 0.05)\) with respect to the cooking time and the fracture force used to break beans. This effect occurred at 140 min for peas and chickpeas.

### 3.7 Total phenolic compounds

In the **blue corn** samples, there was a significant difference \((p < 0.05)\) in the TPC (Figure 4A), with the BCP (raw grain) having the highest value and the BCNM having the lowest value. This difference is due to the process conditions for obtaining Flour and dough.

The process of nixtamalization significantly reduces the concentration of phenolic compounds in blue corn since the temperature and pH conditions favor the solubility of anthocyanins in the cooking water. In addition, other chemical structures that are derived from the polyphenols are affected by the breaking of ester bonds, and as a consequence, the resulting phenols are released into the cooking solution. Most of these compounds are found in the pericarp of the grain and are eliminated during the washing of the nixtamal (Santiago-Ramos et al., 2018). The TPC value of the BCNF was lower than that obtained by (Salinas-Moreno et al., 2012), \((116.5\) to \(94.1\) mg/100 g); this difference may be due to the variety and characteristics of the grain and to the solvent used for the extraction of these components (Camelo-Méndez et al., 2017).

For **beans**, the highest TPC value was obtained in the cooking water (WB), followed by the BP, BF and finally, the BM. These samples presented a significant difference \((p < 0.05)\) due to the processes used to prepare them. A reduction of 30% of the phenolic compounds was found between the BP and the BF; (Aguilera 2010), observed that there was a 21 to 50% reduction in the phenolic compounds in legumes due to the cooking process; however, for the mass, the reduction was 98%, which is due to the leaching process that occurs during cooking, which is the migration of the internal phenolic compounds of the grain into the cooking water (Santiago-Ramos et al., 2018).

In the **chickpea** samples, the CHPF presented the greatest value followed by its cooking water; the grain (CHPP). There was an increase in the phenolic compound content in the CHPF with respect to the CHPP, which could be due to the effect of temperature.
Pea flour (PF) showed a higher concentration of phenols than its cooking water (PW and its mass), which could be due to the thermal treatments (Rosales-Martínez et al., 2014).

**Antioxidant capacity.** The antioxidant capacity (AC) of the processed flours presented a significant difference (p <0.05) for each method. The values obtained by **DPPH** (Figure 4B) were higher than those of **ABTS** due to the affinity of the antioxidant components present in the flours, which are highly hydrophilic in nature and are related to the oxidation of the DPPH radical (Kuskoski et al., 2005). The values obtained by **ABTS** were: PMA 27.87 ± 0.09; HMM 28.82 ± 0.0; PF 36.57; HF 21.97 ± 1.59; PG 8.17 ± 0.09; HG 37.57 ± 0.49 all expressed in mmol ET / 100 g sample. The values of the other samples were not detected by the radical **ABTS**.

In mass samples, there was a 96 to 99% decrease in antioxidant compounds due to the leaching of the compounds into the cooking water, so part of the antioxidant capacity was lost due to the temperature used in the dough-making process, which caused the reduction of other, undetermined components present, such as anthocyanins.

Figure 4B shows that the greatest AC was present in the BCP followed by the BCNF and the BCMN; therefore, the AC of the maize was directly related to the phenolic content. The BCNF value was higher than that reported by (Camelo-Méndez et al., 2017), who obtained a value of 13.1 mmol TE/100 g bs for blue corn. Salinas (Salinas-Moreno et al., 2012), reported percentages of DPPH radical reduction from 34 to 60% for pigmented maize; in the present work, a similar value was obtained (70% reduction percentage).

In legumes, beans (BP) presented the highest AC followed by pea (PP) and CHPP. The AC was significantly different (p <0.05) between the BP, the BF and the mass (BM), with a reduction of 51% for the bean flour and 99% for the dough. This variability is mainly due to the type of legume (Aguilera 2010).

The BF value obtained using the **ABTS** radical was 21.97±1.59, which was similar to that obtained by (Gan Ret et al., 2016), of 23.7 mmol TE/100 g. The CHPF presented a value of 263.53±6.64 mmol TE/100 g, which is higher than that obtained for raw chickpea of 85.14±2 mmol TE/100 g. CHPM had the lowest AC value (0.014±0.001 mmol TE/100 g). The AC value for CHPF was similar to that reported by (Segev et al., 2010), of 259 mmol TE/100 g. The BP presented an AC of 106.36±4.94 mmol TE/100 g, and the BCP had the lowest value (0.076±0.013 mmol TE/100 g). The variation of antioxidant compounds is mainly due to the extraction method used, the genotypes of the species, and the environmental conditions present during cultivation grais (Amarowicz and Shahidi 2017).

### 3.9 Physicochemical characterization of the snacks.

The snacks obtained from the mixture design that incorporated the individual mass of each grain and mixture (in total 19) presented an average humidity percentage of 1.25%, an average diameter of 5.53 ± 0.162 cm and a thickness of 1 mm, with a protein percentage interval from 8.403 to 21.293%, a fiber percentage interval from 3.25 to 4.79%, a fat percentage interval from 2.067% to 7.037, and a fracture force that ranged from 20.27 to 23.24 N. Commercial snacks have a percentage of protein that varies from 5 to 8%, fat from 18 to 37% and an energy content of 461 to 591 Kcal / 100 g (PROFECO. FRITURAS AL DESNUDO 2012), that is, the protein content obtained in the present study was 68 to 166% higher. The snack obtained from 100% corn had the lowest protein content (8.403±0.24%), which was similar to that reported by (Figueroa-González et al., 2010), for a commercial corn snack (8.0±0.14%).

After the snacks were made, the sensory analysis was conducted to choose the best acceptance rate, taking the protein, fat and antioxidant content into account.
3.10 Sensory evaluation. A significant difference (p < 0.05) was observed for the appearance attribute, which was directly related to the color (Figure 5) above. The snacks that presented the best appearance and color score were those that contained pea mass. Regarding the attribute of flavor, the snacks obtained did not present a significant difference (p > 0.05) in flavor scores. The highest score was the snack that contained chickpea mass, which was found in proportions of 13% to 100%. (Kayacier et al., 2014), reported that the addition of chickpea flour in wheat chips generated an increase in acceptability. There was no significant effect (P > 0.05) for consistency and crunch, and the snacks with legumes had the best grades. The snacks with the best scores were 2: CHP, 3: B, 4: P, 14: CHP/B/P and 16: BC/CHP/B/P. The snacks S13 (BC/B/P), S14 (CHP/B/P), S15 (BC/CHP/B/P), S16 (BC/CHP/B/P) and S19 (P/B/BC/CHP), which correspond to different mixtures of 3 or 4 grains, were also chosen as the best in the color, flavor and texture attributes(Figure 5). To include mixtures with corn and legumes, these last 5 snacks were used for the addition of tomato powder. Table 2B shows the properties of the best evaluated snacks in the sensory analysis and includes the values obtained from the snacks with a single grain and those without the addition of tomato powder. The addition of legumes increased the protein content of the corn snack by approximately 63%, a result similar to that obtained by (Figueroa-González et al., 2010), who reported an increase of 44%. There was a 61% increase in protein content in the snacks made from bean-corn mixtures, while Lazou and Krokida 2011, reported an increase of up to 65% in extruded additives with lentils. The mixtures that showed the highest concentrations of protein were those that contained a higher percentage of pea mass. Kayacier et al., 2014, reported protein values of 18.69±0.07 to 34.22±0.84% for a mixture of wheat and legumes. The fat percentage of the chips prepared in this study was 84 to 89% lower than that for commercial snacks. The differences found are due to the characteristics of the raw materials used for their elaboration. The crude fiber percentage of the samples ranged from 3.253 to 4.79%, with the corn snack having the lowest concentration and the chickpea having the highest. The low concentration of fiber for the snack made with corn is due to the loss of the pericarp of the grain during the nixtamalization process (Paredes et al., 2009). In comparison with the commercial snacks, which report from 1 to 3% of fiber on their labels, those obtained in the present work show superior fiber content between 8 and 59%. The fracture strength results for the snacks ranged from 20.27 to 23.24 N, with corn having the lowest value and BC/CHP/B/P having the highest value. The temperature and humidity conditions of the process influence the hardness of the product since lower values for both parameters required less fracture force.

3.11 Snacks added with antioxidants. Tomato powder was added to the masses of the 5 snacks selected in the sensory evaluation (S13: BC/B/P, S14: CHP/B/P, S15: BC/CHP/B/P, S16: BC/CHP/B/P and S19: P/B/BC/CHP) (Figure 4). With regards to microbiological quality, the tomato powder showed an overall absence of mesophiles, coliforms, molds and yeasts. The TPC results of the snacks are presented in Figure 4C, where there is a significant difference (p < 0.05) between the masses and the chips obtained, with an increase of 60 to 80% in the phenolic content of the snacks. The snack, S15 (CB/B/CHP/P), presented the highest phenolic concentration (127.39±14.55 mg GAE/100 g), which was much higher than that obtained in the snack without the addition of tomato powder (0.541 ± 0.004 mg GAE/100 g). The total phenolic content values obtained for the snacks with added tomato powder (94.086 to 127.39 mg GAE/100 g of sample) are within the range established by (Nemš et al., 2015), who reported values of 73 to 290 mg / 100 g in potato chips. The antioxidant capacity (Figure 4D) was in the range of 125.71 to 183.38 mmol TE/100 g for the added masses and from 382.35 to 477.39 mmol TE/100 g for the snack, with snack 14 CHP/B/P, having the highest AC. In the baked snacks with added tomato powder, there was an increase in antioxidant capacity of 64 to 70%. (Dehghan et al., 2010), reported that there was a retention of 15% more lycopene in extruded snacks that had added tomato skin, having found values between 0.50 to 3.84 ppm of lycopene. The antioxidant capacity value obtained in the present work was much higher than that reported by (Nemš et al., 2015), (0.16 to 0.68 mmol TE/100 g). The phenolic compounds contribute to changes in antioxidant activity and the increase in these components when exposed to heat is mainly due to the production of enzymes in the metabolic pathway that favor the production of this type of compound. The addition of tomato powder favored the sensory characteristics of the 5 samples since there was no significant difference (p > 0.05) in the appearance attribute between them, unlike in the snacks without tomato powder. The parameters evaluated for the sensory test did not show a significant effect (p >0.05).

4. CONCLUSIONS

Obtaining a functional snack by mixing masses of legumes and cereals is feasible and allows for the acquisition of chip-type snacks with higher protein and fiber percentages than commercial snacks, which are considered junk foods due to their deficit of these components. Regarding the fat content, the use of baking as the preparation method resulted in snacks with 84% less fat. The use of tomato skin and seeds, resulted in increased phenolic and fiber content and provided color and flavor to the snacks. Using
a proportional mixture of blue corn, beans, chickpeas and peas, it was possible to create a healthy snack with both high protein content and high antioxidant content. This proposed snack with functional compounds as anthocyanins, polyphenols and carotenoids, can satisfy hunger and grant health benefits also they inhibit free radical reactions protecting cells and avoiding oxidative stress.

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**Conflict of Interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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