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Quality evaluation of tortilla chips made with corn meal dough and cooked bean flour

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Abstract: A mixture of cornmeal dough and cooked bean flour (BF) was prepared at different ratios (50/50, 60/40, and 70/30 w/w), and processed to chips. Viscosity profile, temperature of gelatinization and enthalpy, texture, protein content, and *in vitro* digestibility were measured. Pasting temperature tended to be lower when the flour bean concentration was lower. Maximum viscosity increased significantly in both samples (dough mixture and chips) when the BF concentration was lower. In general, gelatinization temperature remains constant, while the heating enthalpy was higher with lower BF concentration. The addition of BF was correlated with greater crispiness, suggesting improved chip texture at higher BF concentrations. The final protein content in the corn-bean chips was very similar, despite the concentration of BF used. Protein digestibility in the chips was affected by the proportion of BF added, being higher when the amount of the BF was lower.

Subjects: Beverages; Food Additives & Ingredients; Food Science & Technology; Preservation; Product Development

Keywords: cornmeal dough; bean flour; viscosity; texture; chips

1. Introduction

Snacks have gained importance and acceptability worldwide in recent years and are now part of the contemporary culture. Typically, snacks are dense calorie foods consisting of high carbohydrate and fat content, but with respect to the amount of protein content, they have low nutritional value. Because they traditionally provide less than 2% of the protein requirement, they are referred to as foods that provide "empty calories" (Almeida, Valencia, & Higuera, 1990). The current trend in the

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L.A. Ochoa-Martínez, is researcher professor in the Technical Institute of Durango, México, in the Chemistry and Biochemistry Department. She works on research projects about food processing and new products development from fruits, vegetables, and cereals. Her research involves new products development, studying the preservation of main components either as the complete matrix or as extracts. Her research studies also involve shelf life and sensory evaluation. She uses traditional processing methods such as dehydration (convective, osmotic, spray drier), as well alternative and complementary technologies such as microwaves and ultrasound. This research deals about the enrichment of a corn snack by adding a popular legume in México like beans.

PUBLIC INTEREST STATEMENT

The consumption of snacks all around the world is constantly increasing, as a result, it is necessary to offer more nutritional products. In that sense, it is important to try the enrichment of traditional products to give an added value from the nutritional and economical point of view. This experimental work was conducted to assess the feasibility to produce a corn snack containing a certain proportion of bean flour and having the proper characteristics of a snack.

food industry is to produce more nutritive snacks, rather than try to eliminate snacks from the diet, largely because of their economic value. Incorporating nutrients directly into snacks is an important means of ensuring consumers have healthy diet choices. For human nutrition, cereals provide an important source of energy and proteins, but a diet based solely on cereal is deficient in essential aminoacids like lysine (Shewry, 2007). Supplementing cereal-based diets with legumes can improve the nutritional status. Cereals combined with legumes offer an important source of lysine and tryptophan adequate to compensate for the lower values found in cereals. Corn and beans are the main components of the basic Latin American diet, and this is especially true for Central America. Legumes, such as beans, have a higher content of protein and minerals, therefore, bean flour (BF) may be a good additive to enrich corn-based products and increase their nutritional value. Recent studies reported that extruded snacks prepared from a mixture of beans and corn starch in a 7:3 proportion, crude protein was increased 12-fold (Anton, Fulcher, & Arntfield, 2009). Although the nutritional value may be improved, the textural properties may determine acceptability of the product. Therefore, the aim of this investigation was to evaluate the effect of BF addition on its physical and nutritional properties in corn chips.

2. Materials and methods

2.1. Raw materials

Corn (Cafime variety) harvested in Durango, México, and beans (Bayo Victoria variety) harvested in Sinaloa, México were used in this study. Corn and beans were cleaned to eliminate impurities and dirt.

2.2. Process used to obtain cornmeal dough and BF

Corn was subjected to the traditional process of nixtamalization: corn kernels were cooked in water containing 1.5 g/100 g $Ca(OH)_2$ at 92°C for 30 min, and then steeped for 12 h in water. The remaining liquid was drained and the “nixtamal” was ground in a stone mill (Villamex, Guadalajara, Jalisco, México) with a 0.25 mm gap between stones to obtain the cornmeal dough (CM), it was stored under refrigeration until further use. To prepare the cooked BF, beans were washed under tap water to remove soil and then boiled in water for 60 min in a pressure cooker (Ecko, México) according to Rocha-Guzmán et al. (2005). Once cooked, the beans were allowed to cool and then were milled with a small amount of the cooking broth in a blender (Osterizer, México) operated at low speed to obtain a bean paste. The paste was then dehydrated in an oven (Ética, Equipamientos Científicos S.A. México) for 5 h at 45°C. Finally, the dried bean paste was ground in a mill (Laboratory Mill Type 3600, Perten Instruments AB) at 1680 rpm, and sieved through a 300-μm mesh (No. 60) to obtain the BF. The cooked BF was stored in plastic containers under refrigeration until needed.

2.3. Preparation of mixtures

Cornmeal dough and cooked bean flour (CM/BF) were mixed according to these ratios: 50/50, 60/40, and 70/30 (w/w), and were coded as: M1, M2, and M3, respectively. The mixtures were combined with water and salt in a food processor (Kitchen Aid) to obtain the dough with a moisture content of 56–57 g/100 g and salt 1.5 g/100 g. Prepared doughs were stored in plastic bags under refrigeration to avoid dehydration. The mixtures (M1, M2, and M3) were evaluated on the basis of their viscosity profile, gelatinization temperature and enthalpy.

2.4. Preparation of tortilla chips

The mixtures CM/BF (M1, M2, and M3) were passed through a manual tortilla-rolling machine (TM-G, Durango, México) to obtain tortillas with a thickness of 3 mm. Triangular tortillas that were 7 cm on each side were obtained using a specially designed corer. Tortilla triangles were first cooked on a metal hot plate at 280 ± 10°C for 30 s on one side and 25 s on the other side (Gaytán, Martínez, & Morales, 2000) and then allowed to cool for 1 h before being fried with vegetable oil (Canola and Linseed oil mixture, Capullo brand) at 180°C for 45 s, as reported by Gaytán et al. (2000). Chips were classified as treatments T1, T2, or T3, according to the cornmeal/bean flour proportion (M1, M2, and

M3), respectively. Chip samples were evaluated for viscosity profile, gelatinization temperature and enthalpy, texture, protein content, and *in vitro* digestibility of protein.

2.5. Analysis of dough mixtures and chips

2.5.1. Viscosity profile

Viscosity as a function of temperature was determined using a Rapid Visco Analyzer (RVA, Newport Scientific, Warriewood, Australia). Moisture content was determined and adjusted to 14 g/100 g (w.b.). For the profile, 4 g of sample (dry weight basis) was mixed with distilled water to reach a constant weight of 28 g per sample. The suspension was mixed for 2 min using rotary blades to ensure a uniform dispersion and to stabilize the temperature at 50°C. Then, the temperature was increased to 92°C at a constant speed of 5.6°C per minute and finally, the mixture was cooled at 50°C for 7.5 min (Becker, Hill, & Mitchell, 2001).

2.5.2. Gelatinization temperature and enthalpy

Gelatinization temperature and enthalpy were determined using a calorimeter model DSC550, (Instrument Specialists Incorporated, Spring Grove, IL), previously calibrated with indium. Samples (2 mg) were weighed directly in aluminum sample pans and then deionized water was added with a microsyringe to obtain a suspension with 65–75% of moisture (dry basis). Samples were hermetically sealed and allowed to equilibrate for 15 min at ambient temperature and then heated to 30–120°C at a heating rate of 10°C/min. An empty pan was used as a reference for all the runs.

2.5.3. Analysis of chip texture

Chip texture was evaluated using a universal texture analyzer (TA-XT2i Texture Analyzer, Surrey, UK), applying a rupture test (force of compression) to determine the necessary force to break the chip. A spherical probe 6.325 mm diameter with a hollow cylindric base of 18 mm diameter was used. Testing was carried out at a speed of 1.0 mm/s until the sample was broken. The test was repeated in 10 samples for each treatment. In this determination, a commercial sample (Doritos) was used as a control (CS).

2.5.4. Protein content and digestibility in vitro of chips

Raw protein content (N × 6.25) was determined using a micro-Kjeldahl method (40–70, AACC, 2000). Protein digestibility *in vitro* was measured in duplicate using the method described by Hsu, Vavak, Satterlee, and Miller (1977).

2.6. Statistical analysis

Analysis of variance (ANOVA) was applied to analyze data using a Generalized Lineal Model (GLM) technique, and statistical differences were evaluated using Tukey's multiple comparison tests ($p < 0.05$). Data analyses were done using Statistica (version 6.0, Statsoft, Inc., Tulsa, OK).

3. Results and discussion

3.1. Viscosity profile in dough mixtures and chips

Viscosity properties in dough mixtures and chips are presented in Table 1. Pasting temperature (TP) is an indicator of the minimum temperature needed to cook the product (Singh, Richa, Rhythm, Mukti, & Jaghmohan, 2009). It was found that TP was higher in samples containing a higher proportion of beans (M1 and T1). The increase of TP ensured that the starch granule is protected during processing due to a structural rearrangement (Yanica, Chureerat, & Vilai, 2009), this could imply that the bean starch was subjected to less damage during processing. Product viscosity depends on the degree of gelatinization of starch granules and the extent of disruption of the molecular structure (Iida, Tuziuti, Yasui, Towata, & Kozuda, 2008). This study revealed higher values ($p < 0.05$) for maximum viscosity (V_{max}) in dough mixtures (M) and the V_{max} increased for both samples (M and T) as the concentration of the BF was decreased. The above behavior denotes major degree of starch gelatinization during the chips processing, that suggesting degradation of the starch structure by the

Table 1. Viscosity properties in samples of dough mixtures and chips

Sample (n = 3)	TP (°C)	V_{max} (cP)	V_{min} (cP)	V_{fin} (cP)
Dough mixtures				
M1	78.8 ± 0.24[a]	1,630.5 ± 27.50[c]	1,157.5 ± 27.70[c]	3,050.0 ± 125.8[c]
M2	76.8 ± 0.07[b]	2,161.0 ± 48.10[b]	1,499.5 ± 27.57[b]	4,088.5 ± 60.10[b]
M3	77.4 ± 0.28[b]	2,451.5 ± 38.90[a]	1,769.5 ± 28.90[a]	4,841.0 ± 103.2[a]
Chips				
T1	79.0 ± 0.14[a]	740.00 ± 82.10[c]	732.5 ± 77.10[b]	1,134.5 ± 55.80[b]
T2	78.6 ± 0.31[a]	914.00 ± 65.10[b]	904.5 ± 70.10[a]	1,526.0 ± 96.70[a]
T3	78.3 ± 0.17[a]	1,021.5 ± 65.70[a]	880.0 ± 39.50[a]	1,440.5 ± 38.80[a]

Notes: Means with different letter in the same column for samples (M) and samples (T) are significantly different ($p < 0.05$).

Dough mixtures: 50/50 (M1), 60/40 (M2), 70/30 (M3). Chips: 50/50 (T1), 60/40 (T2), 70/30 (T3).

thermal process, and also depending on the flour bean concentration. Arámbula, Barron, González, Moreno, and Luna (2001) and Sahai, Buendia, and Jackson (2001) have pointed out that less processed starch present higher viscosity than a gelatinized starch which does not develop viscosity. In this study, the capacity to develop viscosity was affected on doughs (M1, M2, and M3) and chips (T1, T2, and T3). Heating during the elaboration process (nixtamalization, grinding, cooking, and frying, with frying considered to be the most severe) solubilizes amylose chains and the subsequent reorganization of molecules alters viscosity (Méndez-Montealvo, Sánchez-Rivera, Paredes-López, & Bello-Pérez, 2006; Sefa-Dedeh, Cornelius, Sakyi-Dawson, & Ohene, 2003). Samples T1, T2, and T3 had the lowest viscosity due to molecular dissociation of the main components such as starch, amylose, and amylopectin, as well as solubilization of amylose upon liberation (Jiménez, Salazar, & Ramos, 2007; Ragaee & El-Sayed, 2006). Decreased viscosity was even more pronounced in products (chips) that contained a higher proportion of beans (T1: 740 ± 82.1 cP), probably again related to the cooking step where probably occurred the formation of amylose–lipid complex (Mondragón, Bello-Pérez, Agama, Betancur, & Peña, 2004). V_{fin} was analyzed at each processing step and it was significantly affected by temperature in the linear term, resulting in higher values of V_{fin} for those samples with higher values of V_{max}. This may be due to the reassociations of starch molecules, especially between amylose chains during cooling (Chaunier, Valle, & Lourdin, 2007; Hagenimana, Ding, & Fang, 2006; Jiménez et al., 2007). High V_{fin} values provided evidence that a high proportion of amylose is lixiviated in samples.

3.2. Gelatinization temperature and entalphy

This study revealed that the gelatinization temperature (T_G) was very similar in dough mixtures and chips (Table 2). In general, temperatures reflect the presence of a crystalline structure that maintains starch stability, since it is not completely gelatinized (Rodriguez et al., 1996; Singh, Sandhu, & Kaur, 2004). It was observed that (T_G) tends to decrease in samples with lower concentrations of beans. The T_G value decrease could be due to native starch degradation during processing (Méndez-Montealvo et al., 2006; Serna-Saldivar, Gómez, Almeida, Islas, & Rrooney, 1993). The enthalpy results showed that when the concentration of BF was lower the enthalpy was higher. Lower values of entalphy in the final product (T1, T2, and T3) suggested drastic processing conditions since thermal treatment produces starch gelatinization with a higher degree of disorder. In addition, lower enthalpy in samples with higher bean concentrations (M1 and T1) suggested that the bean starch gelatinized in a greater degree during cooking than the corn starch, which was done during the nixtamalization process.

3.3. Chip crispness

Figure 1 shows the effect of the addition of BF and moisture content on crispness: Control sample (TC) (0.71 ± 0.17), T1 (1.22 ± 0.19), T2 (1.05 ± 0.41) and T3 (0.93 ± 0.16). High flour bean concentration and

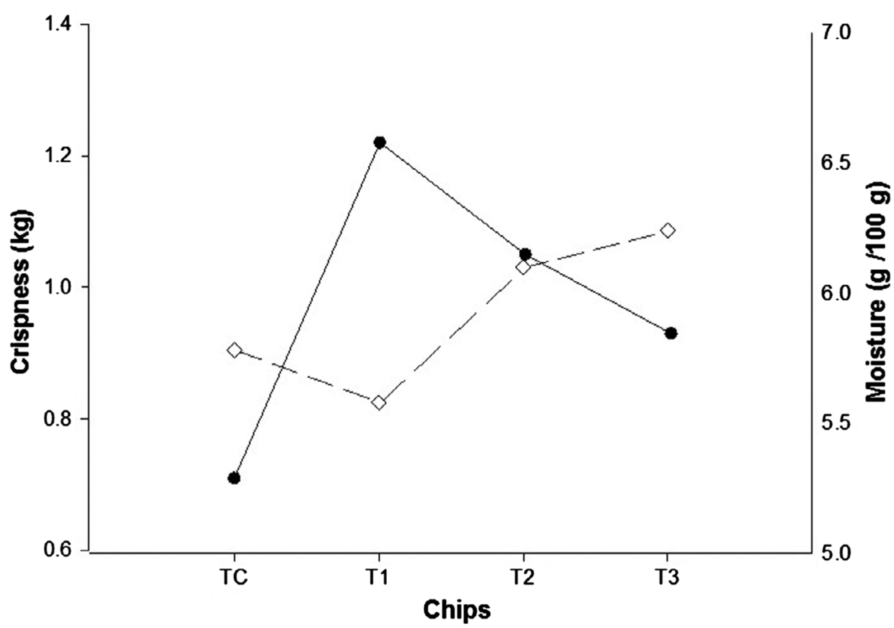
Table 2. Gelatinization temperature and enthalpy during processing for dough mixtures and chips

Sample (*n* = 3)	Gelatinization temperature (°C)	Heating enthalpy (J/g)
Dough mixtures		
M1	79.37 ± 1.29[a]	0.99 ± 0.24[b]
M2	79.30 ± 1.43[a]	1.22 ± 0.31[ab]
M3	78.80 ± 1.87[ab]	1.51± 0.11[a]
Chips		
T1	80.11 ± 0.23[a]	0.48 ± 0.07[c]
T2	80.32 ± 0.42[a]	0.86 ± 0.24[b]
T3	79.33 ± 0.66[a]	1.02 ± 0.12[ab]

Notes: Means with different letter in the same column for samples (M) and samples (T) are significantly different ($p < 0.05$).

Dough mixtures: 50/50 (M1), 60/40 (M2), 70/30 (M3). Chips: 50/50 (T1), 60/40 (T2), 70/30 (T3).

Figure 1. Relation between crispness (●) and moisture content (◇) in the control sample (TC) and chips (T1, T2 and T3).



low moisture content increased chip crispness, which is a critical parameter for chip quality. The crispness values observed in all the corn-bean samples were higher than the values for a commercial product (Doritos) (0.71 kg). The slightly higher values found in this study can be attributed to starch gelatinization, which produces a structure more similar to corn chips, with denser cell walls that require higher force to rupture (Quintero-Fuentes, McDonough, Rooney, & Almeida-Dominguez, 1999).

3.4. Protein content and in vitro protein digestibility of chips

Protein content (Table 3) was higher in prepared chips than in the corn (6.32 g/100 g), but lower than in beans (23.50 g/100 g). Protein in T1, T2, and T3 was 14.14 g/100 g, 13.28 g/100 g, and 13.00 g/100 g, respectively. From the above results, and taking into account the initial protein content in corn, it can be inferred that the addition of BF to corn chips approximately increased twofold the protein in the three chips produced. These values are higher than nutrimental values reported for some commercial products like fritos and doritos from corn (≈2.0 g/100 g). Drago, González, Chel, and Valencia (2007), showed an increase in protein of 47 g/100 g in extrudates of corn-beans in an 85/15 ratio. Protein digestibility values in raw bean and corn were 74.73 g/100 g and 76.33 g/100 g, respectively

Table 3. Protein content and *in vitro* digestibility in raw material and chips

Sample	Protein (g/100 g)	Protein digestibility (g/100 g)
Raw material		
B	23.50 ± 0.01	74.73 ± 0.55
C	6.32 ± 0.00	76.33 ± 0.70
Chips		
T1	14.14 ± 0.00[a]	80.77 ± 0.63[c]
T2	13.28 ± 0.05[ab]	83.39 ± 0.76[b]
T3	13.00 ± 0.92[b]	85.20 ± 0.00[a]

Notes: Means with different letter in the same column for samples (T) are significantly different ($p < 0.05$). Beans (B), C (Corn), Chips: 50/50 (T1), 60/40 (T2), 70/30 (T3).

(Table 3), and the values varied from 80.77 to 85.20 g/100 g for the chips. The above findings are in accordance with the protein digestibility of the raw material, the lower proportion of beans with the higher proportion of corn increases the protein digestibility (T3). Ruiz-Ruiz et al. (2008) reported an *in vitro* protein digestibility of 80% in extrudates of 40/60 (w/w) blend of hard-to-cook beans and quality protein maize. The increase in digestibility after processing can be attributed to the reduction or inactivation of antinutritional factors such as trypsin inhibitors, phytic acid, condensed tannins and polyphenols present in corn and beans (Alonso, Aguirre, & Marzo, 1998, 2000; Ruiz-Ruiz et al., 2008). This study revealed results were similar to the protein digestibility values (83 g/100 g) for extruded BFs as reported by Alonso et al. (2000).

4. Conclusion

This investigation showed that the addition of BF at different concentrations, significantly affected the physical, nutrimental, and textural properties of chips. Based on the revealed results, the mixture corn-bean flour (70/30) was identified as the most appropriate for producing chips from the technological point of view. It was demonstrated that incorporating BF in manufacturing corn chips produced a snack with superior nutritional properties and similar texture attributes to those of corn snacks currently found in the market.

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