Physicochemical and sensory characterization of an extruded product from blue maize meal and orange bagasse using the response surface methodology

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ABSTRACT
The mixtures of blue cornmeal and orange bagasse were processed in a single screw laboratory extruder. We used an experimental design, central composite rotatable, where the factors were as follows: extruder die temperature (153–187°C), feed moisture (146.4–213.6 g/kg), and orange bagasse concentration (32.7–167.3 g/kg). The results were analyzed by surface methodology response to evaluate the effect of these variables on the expansion index, bulk density, penetration force, specific mechanical energy, water absorption, and water solubility index. All independent variables had an effect on the evaluated responses (p ≤ 0.05). The highest expansion index was obtained at a feed moisture content of 146.4 g/kg, orange bagasse (100 g/kg), and 170°C at the exit die. The use of blue maize and orange bagasse can be an alternative to increase the added value of these two raw materials, and to improve the nutritional quality of extruded products ready to eat.

1. Introduction
Snack foods are widely consumed regardless of social status, age or gender. Currently, the production of snacks in Mexico is estimated at around 450,000 tons, with an annual per capita consumption of 3.8 kg, and an annual market value of 3.419 billion. Snacks fried wheat flour and corn represents 36% of the total domestic production, followed by potato chips (27%), corn chips and tostadas (19%), basted and puffed products (11%), peanuts and seeds (4%), and pork rinds (3%) (CANACINTRA, 2017). Extrusion is a versatile and efficient processing method, used for the manufacture of various products such as snacks, nixtamaлизed flour, pet, cattle and fish food; using raw materials such as maize, rice, wheat, potato flour, taro, bean flour, chickpeas and peas, among others (Berrios, Wood, Whitehand, & Pan, 2004; Mensa-Wilmot, Phillips, Lee, & Ettenmiller, 2003; Rocha-Guzmán et al., 2006; Rodríguez-Miranda et al., 2011). Mexico has about 59 different varieties of maize: yellow, red, purple, black, and blue. There are few studies in which the pigmented maize are used as raw materials to be processed by extrusion. Most of these studies are aimed at nixtamalized flour production, mainly evaluating the changes in terms of phenolic and anthocyanins content after processing (Aguayo-Rojas et al., 2012; Mora-Rochin et al., 2010). Zazueta-Morales, Martínez-Bustos, Jacobo-Vaizuela, Ordoñez-Falomir, and Paredes-López (2001), developed a directly expanded snack from blue maize, fortified with calcium, while Navarro-Cortez et al. (2016), developed extruded products with blue maize and different orange bagasse concentrations. In recent years, studies on waste obtained from fruits and vegetables processing have increased in popularity, because these by-products are a promising source of compounds which can be used because of their technological and nutritional properties. Waste worldwide obtained from citrus fruits, has been estimated at more than 15 million tons, which represents a serious environmental problem. This waste consists generally of citrus by-products, has technological and nutritional properties. Waste worldwide obtained from fruits and vegetables processing have increased in popularity, because these by-products are a promising source of compounds which can be used because of their technological and nutritional properties. Waste worldwide obtained from citrus fruits, has been estimated at more than 15 million tons, which represents a serious environmental problem. This waste consists generally of citrus by-products, has technological and nutritional properties. Waste worldwide obtained from fruits and vegetables processing have increased in popularity, because these by-products are a promising source of compounds which can be used because of their technological and nutritional properties. 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seeds and fruit pulp remaining after juice extraction (Laufenberg, Kunz, & Nystroem, 2003). One of the advantages of this type of waste is its content of dietary fiber, and when compared with other fiber sources such as cereals, it has a greater amount of soluble fiber (Gorinstein et al., 2001; Larrea, Chang, & Martínez-Bustos, 2005). The objective of this research was to evaluate the effect of the extrusion temperature, feed moisture and concentration of orange bagasse on the physicochemical and sensory properties of directly expanded extruded products, made from blends of blue maize and orange bagasse using a central composite rotatable design.

2. Materials and methods

2.1. Raw materials

Blue maize (Zea mays L.) obtained from a local market at Actopan, Hidalgo, Mexico. The orange bagasse was obtained from an establishment that sells fresh juice in Pachuca city, Hidalgo, Mexico.

2.2. Obtaining flour

Blue maize was milled in a turbine mill (pulvex, p200, DF, Mexico City). Orange bagasse was dehydrated at 67°C for 12 h in an oven with forced air circulation (Thermolyne 9000, USA), thereafter was ground in a blender (Oster, model BPST 02-b, USA) and sieved to a 120 µm particle size. Orange bagasse flour was mixed with blue cornmeal at different concentrations according to the experimental design; the obtained blends were adjusted at different feed moistures with distilled water (Table 1).

2.3. Extrusion process

After setting the desired moisture content, the samples were fed to a single screw laboratory extruder (Brabender Instruments Inc., model 20DN/8–235-00, CW, Germany) at a feed rate of 30 rpm/min. The extruder barrel is divided into two heating zones that keep a constant temperature of 80 and 120°C, respectively. The third zone, which corresponds to the matrix and die, was varied according to the experimental design. The screw speed was kept constant at 170 rpm, it was used a die with an outlet diameter of 3 mm and a screw with a compression ratio of 3:1.

2.4. Characterization of extruded products

2.4.1. Expansion index

The expansion index (EI) of the extruded products was calculated by dividing their diameter by the inner diameter of the exit die. 20 determinations were performed per treatment.

2.4.2. Bulk density

The bulk density (BD) (kg/m³) was calculated by dividing the weight of the extruded piece, by its apparent volume (m³). Apparent volume was obtained as follows:

\[ V = \frac{1}{4} \pi d^2 h \]

where \( d \) (m) is the diameter of the extruded product and \( h \) (m) is the average length.

2.4.3. Penetration force

The force required (PF) to penetrate the expanded product was measured with a texture Analyzer TA-TX2 (Stable Micro Systems, Ltd., UK). Extruded samples were placed horizontally on a platform and penetrated with a 2 mm cylindrical flat tip probe. Probe descent rate was 2 mm s⁻¹, and maximum penetration distance was 3 mm. Thirty measurements were taken per treatment and values were reported as newtons (N).

2.4.4. Absorption and water solubility index

The water absorption index (WAI) and water solubility index (WSI) were determined according to the method proposed by Anderson, Conway, Pfeifer, and Giffin (1969), modifying the weight of sample 3 to 1 g.

2.4.5. Specific mechanical energy

The specific mechanical energy (SME) was calculated using the torque values (N*m), the screw speed (vt, rpm), and the feed flow \( (F, \text{ g/min}) \) according to the next equation (Batterman-Azcona, Lawton, & Hamaker, 1999).

\[ EME = \frac{(2\pi \times T \times vt)}{F} \]

2.4.6. Sensory analysis

The hedonic sensory evaluation was performed with 80 untrained students of the Food Chemistry Degree of the Autonomous University of Hidalgo State (UAEH), 42 men and 38 women, age ranging between 19 and 23 who usually eat snacks. The students evaluated 3 extruded snacks with different orange bagasse content \( (A = 60, B = 100, \text{ and } C = 140 \text{ g/kg}) \). The evaluated parameters in the extruded snacks were color, texture, flavor (orange and bitter) and overall acceptability using a 7-point hedonic scale (where 1 = extremely unpleasant to 7 = extremely pleasant). Panelists rinsed their mouth with water after tasting each sample.

2.5. Experimental design and statistical analysis

A central composite rotatable experimental design with three independent variables were used: feed moisture, die temperature and orange bagasse concentration (Table 1). The dependent variables were as follows: EI, BD, penetration force (PF), SME, WAI, and WSI. The data were analyzed and adjusted to a second order regression model, and the regression coefficients were obtained. The response surface graphs were obtained using the Design Expert 7.1.6 Statistical Package (Stat-Ease, Inc., MN, USA). The significance of each term in the regression equation was examined by analysis of variance (ANOVA) for each response. To relate each answer with extrusion temperature, feed moisture, and orange bagasse concentration, the following response surface model with linear terms, quadratic and interactions was used.

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Table 1. Experiment design, rotatable composite central, \( a = 1.682 \).

| Variable               | Level          |
|------------------------|----------------|
| Temperature (°C)       | -1.682         |
|                        | -1             |
|                        | 0              |
|                        | +1             |
|                        | +1.682         |
| Moisture feed (g/kg)   | 153.18         |
|                        | 160            |
|                        | 170            |
|                        | 180            |
|                        | 186.82         |
| Wasted orange (g/kg)   | 146.4          |
|                        | 160            |
|                        | 180            |
|                        | 200            |
|                        | 213.6          |
| Temperature (°C)       | 153.18         |
|                        | 160            |
|                        | 170            |
|                        | 180            |
|                        | 186.82         |
$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 + \beta_{11} x_{11} + \beta_{22} x_{22} + \beta_{33} x_{33}$

3. Results

3.1. Calculated coefficients of the adjusted model

Table 2 shows the coefficients of multiple linear regression and the coefficients of determination of models for the evaluated responses. These regression coefficients show that the extrusion temperature in the linear term presented statistically significant effect on EI, PF, WAI, and SME. Feed moisture and orange bagasse concentration showed statistically significant effects on the linear term for all the evaluated responses. The temperature–moisture interaction did not show a significant effect on WSI, while the temperature–orange bagasse concentration interaction presented significant effect on all the evaluated responses. Moisture–orange bagasse concentration interaction showed no significant effect on PF. Temperature, moisture, and orange bagasse concentration in their quadratic terms presented significant effect on all analyzed responses.

3.2. Characterization of extruded products

3.2.1. Expansion index (EI) and bulk density (BD)

Figure 1(a) shows that the highest EI (2.82) at an orange bagasse concentration of 100 g/kg was obtained at 170°C and 146.4 g/kg moisture. In Figure 1(b), with feed moisture set at 180 g/kg, the highest EI was obtained at 187°C and the lowest orange bagasse concentration, and the lowest EI was obtained at high orange bagasse concentrations and high die temperatures. Figure 1(c) shows that the highest EI was obtained at low moisture, an orange bagasse content of 100 g/kg, and a temperature of 170°C. EI experimental values obtained for all tests run were within a range of 1.65 ± 0.081 to 2.82 ± 0.108. The expansion process in extruded products is complex; it involves dough characteristics such as elasticity and flow resistance, as well as the water steam pressure on each bubble generated within the dough. When the mechanical shearing into the extruder exceeds the shearing tolerance of the bubble surface, it breaks causing a decrease in the expansion (Wang, Ganjyal, Jones, Weller, & Hanna, 2005). The expansion of the extruded products is governed by a change in pressure. The melt dough coming out the extruder undergoes a pressure drop, causing the sudden evaporation of moisture, generating the expansion of the extruded product (Arhalias, Bouvier, & Legrand, 2003), besides transforming the dough into a rigid and brittle product, losing molecular mobility and moisture. Oke, Awonorin, Asiedu, and Aiyedun (2012) studied the effect of moisture content on EI and concluded that decreasing the moisture content increases the force necessary for conveying the melt dough within the barrel, exerting greater pressure on the die, allowing a greater expansion of the extruded product. The EI decrease when increasing the content of orange bagasse, this is due to a dilution effect on the total starch content, affecting the elastic properties of the matrix (Delgado-Nieblas et al., 2012; Robin, Bovet, Pineau, Schuchmann, & Palzer, 2011; Yağcı & Göğüş, 2008). Robin et al. (2012) reported a decrease in the EI values, due to a breakdown of air bubbles when their membrane becomes thinner and reaches bran particles. The breaking of air bubbles may be due to a weak or no interaction between the starch and bran molecules at the interface; similar postulates have been published by Moraru and Kokini (2003), mentioning that fiber molecules alter the continuous dough structure preventing its deformation during expansion, since the fibers align as the flow into the extruder increases the mechanical resistance. The decrease in EI after 170°C has been related to an excessive breaking of the molecules that make up the starch, which weakens the network formed inside the extruded product (Meng, Threnien, Hansen, & Driedger, 2010). El-Dash (1981) reported that the decrease in the EI at high temperatures could be due to the fact that water vaporization is very violent, breaking the structure and decreasing the expansion.

Figure 1(d) shows the effect of the variables die temperature and feed moisture in BD at a fixed content of 100 g/kg of orange bagasse, as the feed moisture increases BD increases. At high feed moisture contents and increasing the extrusion temperature BD decreases, while at low feed moisture contents and increasing the extrusion temperature BD increases. Figure 1(e) shows an increase in BD by increasing the orange bagasse content and the extrusion temperature, to a constant moisture of 180 g/kg, while in Figure 1(f) the effect of feed moisture and orange bagasse content on BD at a temperature of 170°C is presented, observing an increase in BD due to orange bagasse and feed moisture. The BD values for all treatments are between 182.70 ± 22.95 and 594.9 ± 68.70 kg/m³, the highest BD obtained was for the product that presented the lowest EI, while the lowest one was obtained for the product with the highest EI. The decrease in BD as EI increases is due to an increase in the extruded product volume, but with a lower weight. Sacchetti, Pittia, and Pinnaivaia (2005) reported a decrease in BD and hardness of the extruded products, increasing the extrusion temperature. Dehghan- Shoar, Hardacre, and Brennan (2010) reported that products containing fiber have the

| Response | Intercepts | Linear terms | Interactions | Quadratic terms | R² |
|----------|------------|--------------|--------------|-----------------|----|
| EI       | −10.04     | 0.26         | −1.11        | 0.29            | 4.09E−3 | −2.52E−3 | 9.66E−3 | 9.32E−4 | 5.53E−3 | −3.3E−3 | 0.80    |
| BD       | 965.07     | −12.77       | 17.48        | −10.96          | −0.19   | 0.09      | −0.27   | 0.045  | 0.65    | 0.08    | 0.73    |
| FP       | −4641.74   | 88.04        | −31.73       | 124.38          | −3.50   | −1.55     | 0.89    | −0.35  | 17.98   | 0.11    | 0.72    |
| WAI      | −23.33     | −0.33        | 0.93         | 0.064           | −0.01   | 2.43E−3  | −8.35E−3| 1.47   | 0.03    | −4.51E−3| 0.76    |
| WSI      | −107.88    | 3.72         | −22.58       | −40.66          | −0.15   | 0.24      | 2.53    | −0.02  | −0.14   | −0.04   | 0.71    |
| SME      | −2.34E5    | 2965.48      | 14,999.48    | 225.52          | −172.67 | −0.21     | −7.34   | −8.82  | −11.86  | −2.78   | 0.84    |

Bold numbers indicate significant parameter estimates ($p < 0.05$). Negative coefficients indicate a decrease in the value of the studied response, while positive coefficients indicate an increase.

Números en negritas indican estimaciones significativas de los parámetros ($p < 0.05$). Coeficientes negativos indican una disminución en el valor de la respuesta estudiada, mientras, coeficientes positivos indican un incremento en la respuesta.
ability to absorb water, resulting in products with higher BD and lower EI, generating more compact products. Similar effects were reported for extruded products incorporating okara (Rinaldi, Ng, & Bennink, 2000). Meng et al. (2010) reported an increase in BD by increasing the feed moisture, as well as an inverse relationship between EI and BD.

3.2.2. Penetration force (PF)

Figure 2(a) shows the effect of temperature and feed moisture on the PF at a concentration of 100 g/kg orange bagasse. In this figure it can be seen that the PF increases when increasing the feed moisture and increases when increasing the extrusion temperature. Figure 2(b) shows the effect of orange bagasse in PF with a moisture content of 180 g/kg, which shows that the highest PF is obtained with high levels of orange bagasse and high temperatures. The hardness of the different products varied from 19.21 ± 1.355 to 48.86 ± 6.023 N. The hardness of an extruded product is inversely related to EI and directly to BD. The relationship of hardness with EI is due to the fact that more expanded products have pores with thinner walls, decreasing the force necessary to break the product (Pérez-Navarrete, González, Chel-Guerrero, & Betancur-Ancona, 2006), conversely, slightly expanded products have a higher number of pores with thicker walls, increasing the force necessary to break the product.
pores per unit volume, increasing the pore thickness, fiber addition has been reported to increase the hardness of extruded products, because it interferes with the formation and growth of air bubbles (Ainsworth, Ibanoğlu, Plunkett, Ibanoğlu, & Stojceska, 2007). The decrease in hardness due to the effect of the orange bagasse content agrees with that reported by Altan, McCarthy, and Maskan (2008), who used tomato peel as a source of fiber.

3.2.3. Specific mechanical energy (SME)

Figure 3(a) shows the effect of the die temperature and the feed moisture on SME at a concentration of 100 g/kg orange bagasse, observing that at low temperatures (153°C) and high temperatures (187°C) SME increases with increasing feed moisture from 146.4 to 213.6 g/kg. By increasing the extrusion temperature from 153 to 170°C, the SME increases, >170°C the SME decreases. The highest values of SME were obtained both at low temperatures (153°C) and at high temperatures (187°C), at the highest moisture content tested. When the feed moisture is increased there is a greater amount of water available to be bound by the starch or the pectins present in the orange bagasse increasing the viscosity of the mixture. The effect of the temperature on SME could be related to the degree of gelatinization of the starch, where possible to 170°C the greater degree of gelatinization of the starch is obtained, higher temperatures possibly have an impact on the viscosity of the dough, decreasing the torque in the extruder motor and SME (Altan et al., 2008). The SME applied to the extruded material plays an important role in the conversion of the starch, greater SMEs have usually been related to a higher degree of starch gelatinization (Meng et al., 2010). Figure 3(b) shows the effect of the extrusion temperature and the concentration of the orange bagasse on SME at a moisture content in the mixture of 180 g/kg. The figure shows an increase in SME by increase the orange bagasse content and a decrease by increase the temperature of the die. The increase in the SME due to the concentration of orange bagasse is due to an increase in the viscosity of the dough, which can be attributed to the presence of thickening agents in the orange bagasse such as pectins, which have the ability to bind water and increase the viscosity of the mixture, also during the extrusion process, components such as cellulose, undergo modifications due to the mechanical shearing, exposing the hydrophilic groups of the cellulose to water, increasing the sites of binding. Figure 3(c) shows the effect of feed moisture and orange bagasse on SME at a temperature of 170°C. Observing an increase in the SME at the lowest moisture tested and increasing the orange bagasse content, observing similar results with low concentrations of orange bagasse as the moisture content increases. The lowest SME was obtained at a temperature of 170°C, 146.4 g/kg feed moisture, and 100 g/kg orange bagasse concentration.

3.2.4. Water absorption index and water solubility index (WAI and WSI)

Figure 4(a) shows the effect of the interaction between the extrusion temperature and the feed moisture at a 100 g/kg orange bagasse content, in that figure it is seen that by increasing the moisture content at low temperatures, the WAI increases, as well as by increasing the extrusion temperature at low moisture contents. At 213.6 g/kg moisture content over the entire range of studied temperatures, the WAI decreases. The increase of the WAI when increasing the feed moisture is due to the water lubricating effect; decreasing the viscosity, the residence time and mechanical shearing in the dough, reducing the starch degradation. Water acts as a plasticizer in polymers, promoting the mobility of their chains, facilitating deformation and fluidity, which leads to a decrease in viscosity (Lewicki, 2004; Roos & Karel, 1991). Figure 4(b) shows the effect of feed moisture and orange bagasse concentration at 170°C, in which an increase in WAI is observed by increasing the orange bagasse content at low moisture. At low concentrations of orange bagasse (32.7 g/kg) and as the moisture content increases, water absorption capacity is favored. The WAI values obtained are in the range of 3.66 ± 0.110 and 5.22 ± 0.14 g absorbed water/g sample bs. Some authors have reported a decrease in WAI by increasing the content of a fiber source due to a starch dilution effect (Robin et al., 2011), whereas in the present study WAI increases because the orange bagasse has pectins, which have the ability to form gels and absorb water. The ability of the fiber to absorb water depends on its physicochemical properties and the amount of soluble fiber it contains (Carrasco-Valencia, Acevedo-De la Cruz, Icochea-Alvarez, & Kallio; Zhang, Bai, & Zhang, 2011). Marin, Soler-Rivas, Benavente-García, Castillo, and Pérez-Alvarez (2007), reported that in waste generated by...
The citrus processing industry, pectin content is in the range of 250–300 g/kg of total fiber and that the water absorption capacity increases with the amount of soluble fiber. Larrea et al. (2005), report an increase in the water absorption capacity of the orange bagasse subjected to the extrusion process.

The WSI increases when the extrusion temperature increases from 153 to 170°C and by increasing the orange bagasse content, >170°C WSI decreases (Figure 4(c)) while increasing the feed moisture WSI decreases (Figure 4(d)). Altan, McCarthy, and Maskan (2009), they found an increase in solubility by increasing the temperature of the extruder die around 150°C due to an increase of gelatinized starch and thus the soluble solids. During the extrusion process, the dough is subjected to mechanical shearing, high pressures, and temperatures, breaking covalent and non-covalent bonds between carbohydrates and protein associated with the fibers, as well as the breaking of the hydrogen bonds in the crystalline structure of starch, originating the formation of smaller molecular fragments that are more soluble. The WSI reduction as temperature increases could be caused by an increase in the interactions between degraded starch, protein, insoluble fiber, and lipids. These interactions could increase the molecular weight of the formed complexes, causing a decrease in WSI. A high solubility is a characteristic of over processed products, which results in an increase in the decomposition of polymers present in the raw material (starch and dietary fiber) to soluble in water forms, which is not desired, because products with a high solubility are products that can be rapidly digested and absorbed, dangerously modifying the glycemic index when consumed (Guillon & Champ, 2000). Some breakfast cereals have WSI values of 500 g/kg. The solubility index for the different treatments is in the range of 50.8 ± 6.34 to 160.3 ± 3.96 g/kg, with the highest solubility at low moisture contents. The solubility in extruded products will depend on the processing conditions (raw material composition, screw speed, moisture used, as well as extrusion temperature and die outlet diameter).

3.2.5. Sensory analysis

Three samples out of 20 were selected for the sensory analysis, the selected samples were the ones that presented the highest EIs, the selection is mainly due to the EI correlating directly with the products hardness and therefore with their texture. The averages of the ratings given to each product by panelists are shown in Table 3. The extruded product that presented the highest color acceptability value was A with 60 g/kg of orange bagasse followed by B with 100 g/kg of orange bagasse, whereas the C with 160 g/kg of orange bagasse obtained the lowest value because it had a yellowish brown color not so pleasant to the panelist, likewise the A and B extruded snacks showed the highest values for texture. In terms of flavor, the...
The results showed that it is possible to generate a directly expanded snack with agro-industrial residues and blue maize, which could bring health benefits due to the anthocyanin content of blue maize and the dietary fiber provided by the orange bagasse. This snack could be an alternative to the development of functional snacks, as well as a possible solution for the use of agro-industrial residues, giving them value and a promising use. From the technological point of view, the incorporation of orange bagasse would be a problem at concentrations higher than 100 g/kg, due to the reduction in the EI and the increase in PF, but from the nutritional and functional point of view, it is beneficial because it increases WAI and decreases WSI, which would result in an increase in the viscosity of the bolus and a smaller amount of free sugars, decreasing the glycemic index.
