



**PHYSICAL, MICROSTRUCTURAL AND SENSORY CHARACTERISTICS OF
EXTRUDED AND MICROWAVE-EXPANDED SNACKS ADDED WITH
DEHYDRATED SQUASH**

**CARACTERÍSTICAS FÍSICAS, MICROESTRUCTURALES Y SENSORIALES DE
ALIMENTOS BOTANA EXTRUDIDOS EXPANDIDOS POR MICROONDAS
ADICIONADOS CON CALABAZA DESHIDRATADA**

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Abstract

The objective of this work was to study the effects of the extrusion temperature (T, 93-141 °C), feed moisture content (FMC, 21.27-34.7%), and dehydrated squash content (DS, 0.43-15.57%) on physical, microstructural and sensory characteristics of microwave-expanded snack foods (SF) formulated adding dehydrated squash to a base blend of corn starch-yellow corn. A second order rotatable central composite design and the response surface methodology for data analysis were used. The T and FMC showed a greater effect ($P < 0.05$) on specific volume and moisture of pellets, whereas FMC and DS showed a greater effect on Chroma (C^*) and Hue (H^*) color parameters. The microstructural properties of the snacks evaluated with the Rapid Visco-Analyzer (RVA), Differential scanning calorimetry (DSC) and X-ray diffraction (XRD) were related mainly to the starch gelatinization. Also, the sensory acceptability of snacks added with DS reached almost 79%. The results indicate that it is possible to elaborate SF with acceptable physical and sensory characteristics by adding DS to a base blend.

Keywords: dehydrated squash, extrusion, microstructural properties, sensory acceptability, snacks.

Resumen

El objetivo del presente trabajo fue estudiar los efectos de la temperatura de extrusión (T, 93-141 °C), contenido de humedad de alimentación (CHA, 21.27-34.73%) y contenido de calabaza deshidratada (CD, 0.43-15.57%) sobre características físicas, microestructurales y sensoriales de alimentos BTG expandidos por microondas formulados mediante la adición de calabaza deshidratada a una mezcla base de almidón de maíz-maíz amarillo. Se utilizó un diseño central compuesto rotatable de segundo orden y la metodología de superficie de respuesta para el análisis de datos. La T y CHA presentaron mayor efecto ($P < 0.05$) sobre volumen específico y humedad de los pellets, mientras que CHA y CD mostraron mayor efecto sobre los parámetros de color croma (C^*) y matiz (H^*). Las propiedades microestructurales de las botanas evaluadas con Rapid Visco-Analyzer (RVA), calorimetría diferencial de barrido (DSC) y difracción de rayos X (XRD) fueron relacionadas principalmente con la gelatinización del almidón. Asimismo, la aceptabilidad sensorial de las botanas adicionadas con CD alcanzó casi el 79%. Los resultados indican que es posible elaborar BTG con aceptables características físicas y sensoriales mediante la adición de CD a la mezcla base.

Palabras clave: calabaza deshidratada, extrusión, propiedades microestructurales, aceptabilidad sensorial, alimentos botana.

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1 Introduction

Snack foods are highly consumed, especially by young people. According to studies on consumer trends, more consumers are often replacing the traditional three meals a day with snacks (Beswa *et al.*, 2016). One of the technologies more frequently used to produce snack foods is the extrusion, which is a thermal processing that involves the application of high temperatures, high pressure, short time, and shear force on an uncooked mass, such as cereal foods (Alam *et al.*, 2016). Extruded snack products are mostly cereal based and developed mainly from corn, wheat, and rice (Lourenço *et al.*, 2016). A quality property in snack foods is the specific volume that is a physical parameter and measures the axial and radial expansion. This property basically depends on the viscous and elastic properties of the melted material and is highly influenced by temperature (Hashimoto and Grossman, 2003). The starch (especially from corn) is one of the biopolymers with greater versatility in food and industrial applications (López-García *et al.*, 2017), and is the main ingredient in the manufacture of snack foods. The physical and microstructural parameters of these foods may be influenced by some extrusion factors, such as temperature and moisture (Lazou and Krokida, 2011). On the other hand, a technique used to know the changes on textural and microstructural characteristics of starch molecules in extruded products, is the differential scanning calorimetry (DSC). Furthermore, the changes in starch structure during the extrusion process can be analyzed by means of viscosity profiles in a Rapid Visco Analyzer (RVA) and X-ray diffractograms (Basto *et al.*, 2016). Another important property of extruded foods is the color, because of this is an important factor that influences the acceptability of snack foods. Changes in this parameter may give information about the effect of the processing conditions on aspects such as caramelization, Maillard reaction, degree of cooking, and pigment degradation that take place during the extrusion process. Similarly, the consumer acceptance of extruded foods is due to the convenience, value, attractive appearance, and texture found in these foods (Altan *et al.*, 2008). There are a great variety of snack foods that can be produced by extrusion, including indirectly expanded snacks known as third-generation (3G) or “half products”. Compared to direct expanded snacks, these products have the advantages of an easy

and prolonged storage, having low moisture content and volume (Choi *et al.*, 2007). These foods can be further expanded by microwave heating, which has the advantage of producing fat-free snacks when compared to hot oil expansion. Refined wheat or corn flours are intensively used as a raw material in extruded products such as breakfast cereals or extruded savory snacks, since they provide high expansion capacity and appreciated textural properties (Robin *et al.*, 2015). However, they present a low nutritional contribution. Actually, dietary guidelines issued in the world emphasize the need to include adequate amount of whole-grains and enriched cereal products, to increase complex carbohydrates and fiber in diet. Also, whole grains contain a wide variety of phytochemical compounds, vitamins and minerals (Pardhi *et al.*, 2016). Among these whole grains highlights the yellow corn, which is a cereal with important carotenoid content, whose consumption has been related to the prevention of different diseases (Scott and Eldridge, 2005). Also, like other pigmented grains, the yellow corn contains many secondary metabolites, such as phenolic compounds, with high antioxidant capacity (Delgado *et al.*, 2016). This grain has been used previously for the elaboration of extruded snacks. Navarro-Cortez *et al.* (2016) produced an extruded ready-to-eat snack food using blends of yellow corn and pumpkin (*Cucurbita pepo*) seeds, which could be considered a functional food. Also, to improve the nutritional content of the snack foods, the use of some vegetables has been suggested, having high importance the winter squash, which is a hard shell variety produced in northwestern of Mexico, for which has been reported presents important levels of carotenoids, dietary fiber and phenolic compounds (Jacobo-Valenzuela *et al.*, 2011). Currently, it has not been found published scientific information on microstructural and sensory properties of third generation snack foods added with dehydrated squash. Therefore, the determination of microstructural properties in snacks is important, since they provide information on the changes presented in starch due to the extrusion process, which may impact on different parameters evaluated in these foods, such as the specific volume and retention of moisture by pellets. Also, sensory tests are of great importance in snack foods, because they allow knowing the acceptability of these foods by consumers, and how the acceptability is influenced by attributes such as color, taste and texture. Considering the potential for the technological and economical use of winter squash and whole yellow-corn flours, for the snack

food development, the objective of this work was to study the effects of extrusion processing on the physical, microstructural and sensory characteristics of extruded and microwave expanded snacks added with dehydrated squash.

2 Materials and methods

2.1 Raw materials

The materials used for the elaboration of snack foods were corn starch (IMSA, S.A de C.V., Guadalajara, Mexico), whole grain yellow-corn (*Zea mays* L.) flour, and winter squash (*Cucurbita moschata* D.), cv Cehualca. The yellow corn and the winter squash were obtained from the local market, in the Sinaloa State, Mexico. The dehydrated squash was obtained according the drying method reported by Delgado-Nieblas *et al.* (2017b). After that, both dehydrated squash and whole-grain yellow corn were milled (Hammer mill, Pulvex model 200, Mexico) separately to obtain flours with a particle size $\leq 250 \mu\text{m}$, and

$\leq 420 \mu\text{m}$, respectively. The relation of corn-starch: whole-grain yellow-corn flours used in the different extruded blends, for the different treatments of the experimental design was (1:1), while the concentration of dehydrated squash varied from 0.43 to 15.57% (Table 1).

2.2 Extrusion process

For the preparation of the samples to be extruded, the blends of materials were adjusted to different moisture contents (21.27-34.73%), put into plastic bags, and stored (12-14 h) before being extruded. The samples were fed to a single-screw laboratory extruder Brabender 20DN, model 8-235-00, O HG Brabender, Duisburg, Germany, using a feed rate of 40-45 g/min. The cooking temperature varied from 93 to 141 °C, while the temperatures of feed and die exit zones remained constant at 75°C. An extrusion screw (compression ratio: 2:1) with a speed of 75 rpm was used, while for the formation of pellets was employed a rectangular die (aperture: 20 mm wide, 1.0 mm high, 100 mm long).

Table 1. Experimental design for the extrusion study.

Run	Coded values			Actual values		
	X_1	X_2	X_3	Temperature (°C)	Feed moisture content (%)	Dehydrated squash (%)
1	-1	-1	-1	103	24	3.5
2	1	-1	-1	131	24	3.5
3	-1	1	-1	103	32	3.5
4	1	1	-1	131	32	3.5
5	-1	-1	1	103	24	12.5
6	1	-1	1	131	24	12.5
7	-1	1	1	103	32	12.5
8	1	1	1	131	32	12.5
9	-1.682	0	0	93.45	28	8
10	1.682	0	0	140.55	28	8
11	0	-1.682	0	117	21.27	8
12	0	1.682	0	117	34.73	8
13	0	0	-1.682	117	28	0.43
14	0	0	1.682	117	28	15.57
15	0	0	0	117	28	8
16	0	0	0	117	28	8
17	0	0	0	117	28	8
18	0	0	0	117	28	8
19	0	0	0	117	28	8
20	0	0	0	117	28	8

The formed pellets were cut into pieces of 3 cm long and dried in a room with ventilation and controlled temperature (23-26 °C) during three days, until reach the equilibrium moisture content (AOAC, 2005). Subsequently they were wrapped in sealed plastic bags, and stored under refrigeration conditions (3-5 °C) until analysis.

2.3 Specific volume (SV)

Five pellets per treatment were used for specific volume determination, and a heating-time of 23 s (obtained in preliminary studies) was applied for expansion using a conventional microwave oven (MS-0746T, LG, Monterrey, Mexico) at 950 W and 2450 Hz. This determination was carried out in the expanded products using the volume displacement method, with millet seeds. The reported specific volume values were the mean of 30 determinations and the results were expressed in mLg⁻¹.

2.4 Viscosity profiles

The Viscosity characteristics were evaluated using a Rapid Visco-Analyzer (RVA) model 3C (Newport Scientific PTY Ltd., Sydney, Australia), following the specifications of the operation manual and the suggestions of Zeng *et al.* (1997). The viscosity parameters were analyzed in the samples corresponding to the raw materials, and in the axial ($\pm\alpha$) and central runs of the experimental design, which were ground (< 250 μ m). Samples of three g were weighed and adjusted to 28 g with distilled water, using an aluminum container of the equipment itself. The samples were maintained under constant stirring, being heated to 50 °C for 2 min, then raised to 92 °C with a heating rate of 5.5 °C/min and maintained for 5 min. Finally, the samples were cooled (5.6 °C/min) to 50 °C, and kept at 50 °C for 1 min. The viscosity value at 92 °C ($V_{92\text{ }^\circ\text{C}}$) was reported in centipoise (cP) units.

2.5 Differential scanning calorimetry (DSC)

Thermal analysis by DSC was performed to determine the transition enthalpy, initial (onset), peak (maximum) and final temperatures. These analyzes were carried out on the raw materials and in the axial ($\pm\alpha$) and central runs of the experimental design. The materials were ground, then screened on a 60 mesh screen, obtaining samples with a particle size smaller

than 250 μ m. A calorimeter (Q200, TA Instruments, USA) was used and, the recommendations reported by Aguilar-Palazuelos *et al.* (2006), were followed. For each treatment four milligrams of the sample were placed in standard aluminum pans with 40 μ L, then 12 mg of distilled water were added with a microsyringe. The pan was sealed hermetically, shaken vigorously, and kept at room temperature for 18 h before being heated from 40 to 100 °C at a heating rate of 10 °C/min. The obtained thermograms were analyzed with a TA Universal Analysis software (TA Instruments, USA).

2.6 X-ray diffractograms (XRD)

The X-ray analyses were performed on the raw materials and in the axial ($\pm\alpha$) and central treatments of the experimental design. Samples with a particle size < 250 μ m were mounted on a Philips X'Pert X-ray diffractometer according to the procedure described by Zazueta-Morales *et al.* (2002). The X-ray diffractograms were obtained with a Bragg angle scan of 5°-35° on a scale of 2 θ , with Intervals of 0.02, operating at 30 kV and 16 mA, with CuK α radiation and a wavelength λ = 1.5406 Å.

2.7 Color parameters

To measure the color parameters chroma (C*) and Hue (h*) a tristimulus colorimeter (Minolta, CR-210, Tokyo, Japan) was used. The samples of expanded snack foods of the different treatments were ground to a particle size < 250 μ m and subsequently placed in 5 cm Petri dishes, performing three equidistant readings, and reporting the mean of these.

2.8 Sensory study

This study was performed with the third generation snack foods obtained in conditions of T = 131 °C, FMC = 24% and DS = 12.5% (optimal conditions obtained from a previous study). A general acceptability test was conducted, using a nine-points-hedonic scale, where (1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, 9 = like extremely) (Lim, 2011). The snacks were given to taste to 160 untrained panelists (80 men and 80 women), who performed their university studies.

Table 2. Regression coefficients of the models, significant levels and analysis of variance for the studied responses in extruded snack foods.

	Specific volume (mLg ⁻¹)	Moisture of pellets (%)	Color Chroma (C*)	Color Hue (h*)
Intercept	-124.866	78.036	27.339	254.762
Linear				
T	1.255 (< 0.001)	-0.547 (< 0.001)	---	
FMC	4.021 (< 0.001)	-3.09 (0.005)	-0.119 (0.008)	-12.311 (0.016)
DC	4.152 (< 0.002)	-7.97 (0.943)	2.022 (< 0.001)	-20.329 (0.036)
Quadratic				
T ²	-0.002 (< 0.001)	-0.0003 (0.430)		
FMC ²	-0.020 (< 0.001)	0.006 (0.231)		0.229 (0.019)
DS ²	---	---	-0.046 (0.007)	-0.360 (0.046)
Interactions				
T x FMC	-0.025 (< 0.001)	-0.025 (0.305)		
T x DS	-0.036 (0.190)	0.076 (0.004)		
FMC x DS	-0.158 (0.491)	0.306 (< 0.001)	0.265 (0.012)	1.617 (0.180)
T x FMC x DS	0.001 (0.004)	-0.002 (< 0.001)		
FMC ² x DS				-0.032 (< 0.001)
FMC x DS ²				0.013 (0.012)
R ² _{adj}	0.81	0.72	0.82	0.90
CV	10.84	5.06	3.78	0.79
p of F _(model)	< 0.001	< 0.001	< 0.001	< 0.001
Lack of fit	0.055	0.061	0.396	0.051

T = temperature; FMC = feed moisture content; DS = dehydrated squash; CV = coefficient of variation.

The main criterion for selecting panelists was that they liked to eat some kind of snack food, and that his/her age was ≥ 17 years old. Eighty panelists were asked to read, at least, three times a brief description about the nutritional information of the snack.

Then to observe, to smell, and to taste the product, and finally to fill out a questionnaire expressing their general level of acceptability. The remaining 80 panelists performed the procedure described above

without having received the snack food nutritional information. Also, the attributes of color and flavor of the snacks were evaluated, using the JAR (Just About Right) scale (Epler *et al.*, 1998), with some modifications, being 1 = not enough at all, 2 = not enough, 3 = just about right, 4 = too much, and 5 = far too much, where the most preferred attribute was "just about right". Also, the purchase intention was measured according to the scale reported by

Whitlark *et al.* (1993), with some modifications, where 1 = will buy, 2 = probably will buy, 3 = maybe buy, 4 = probably will not buy, 5 = definitely will not buy.

2.9 Experimental design and data analysis

A five-level central-composite rotatable design was used, with a value $\alpha = 1.682$ (Table 1) and results were analyzed using response surface methodology (RSM). Extrusion temperature (T, °C), feed moisture content (FMC, %), and the dehydrated squash (DS, %) were the evaluated factors, having five levels each factor. The second-order polynomial fitted was:

$$y_i = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 \quad (1)$$

where, y_i is a generic response, X_1 is the temperature, X_2 is the feed moisture content, X_3 is the dehydrated squash, and $b_0, b_1, \dots,$ and b_{23} are the regression coefficients. The analysis of data was performed with the Design Expert statistical software Version 7.1.6 (Stat-Ease, 2008; Minneapolis, USA), whereas the Statistica 7.0 software (Statsoft, 2004; Tulsa, USA) was used to carry out the Pearson correlations.

3 Results and discussion

3.1 Regression coefficients and statistical analysis

The statistical information for the variables of response, specific volume (SV), moisture of pellets and color (Hue (h^*) and chroma (C^*) values) is shown in Table 2. The independent and dependent variables were fitted to the second-order model. It can be seen that R_{adj}^2 values were greater than 0.71 for all the variables of response, the mathematical models were significant ($P \leq 0.001$), and showed no lack of fit ($P > 0.05$). The statistical analysis (Table 2) indicated that the temperature (T) and feed moisture content (FMC) were the factors that showed the more highly significant effect ($P < 0.05$) in their linear and quadratic terms on SV and moisture of pellets. Also, the factors FMC and DS presented the more highly significant effect ($P < 0.05$) in their linear and quadratic terms on the color parameters of snacks. In the analysis of interactions, it was found that the interaction T-FMC showed

significant effect ($P < 0.05$) on the SV response, whereas, the interaction T-DS presented significant effect ($P = 0.004$) on the moisture of pellets, and the interaction FMC-DS showed significant effect ($P < 0.05$) on the moisture of pellets and color parameter C^* .

3.2 Specific volume (SV)

Specific volume is a physical parameter of quality for third generation snacks (TGS), being preferred high values for it. In the Figure 1a is shown the effect of T and FMC on the SV of TGS at constant DS = 8%.

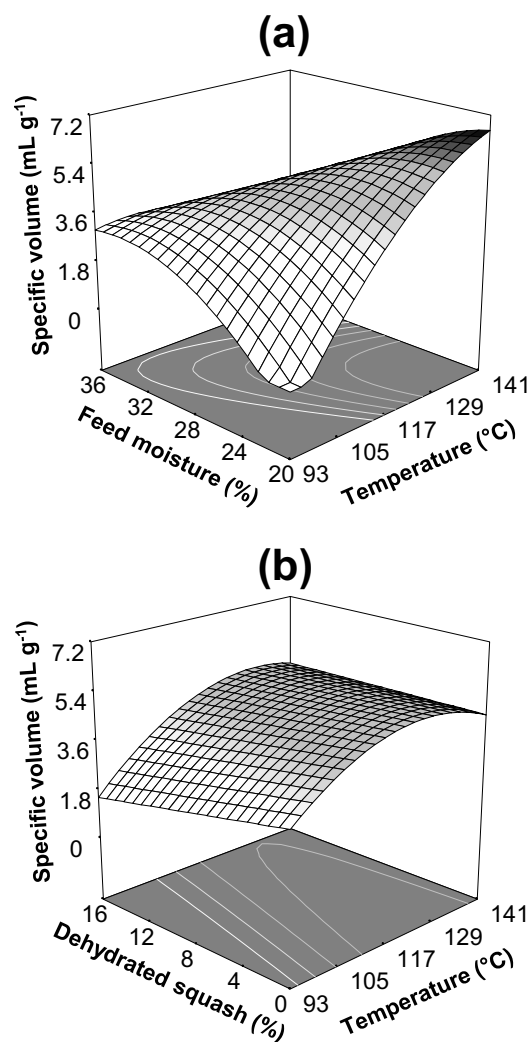


Fig. 1. Effect of temperature (T) and feed moisture content (FMC) (a, at DS = 8%), and the addition of dehydrated squash (DS) (b, at FMC = 28%), on the specific volume of extruded third generation snack foods.

This parameter showed a moderate correlation with the T factor ($r = 0.63$, $P = 0.005$). It can be observed that the highest values of SV ($> 6 \text{ mLg}^{-1}$) were presented by combining T ($> 129 \text{ }^\circ\text{C}$) and FMC ($< 24\%$). This behavior may be due to an improvement of the viscoelastic properties caused by the increase in the extrusion temperature, which could have promoted a greater modification in the structure of the starch. The above mentioned could have caused greater entrapment of water, which subsequently served as an expansion vehicle in the microwave oven, due to the formation of air bubbles. According to Lee *et al.* (2000) the pellets expanded by microwave produced from corn starch presented the highest volumes at high extrusion temperatures (90 or $110 \text{ }^\circ\text{C}$). These authors reported that pellets with levels of gelatinization of $\sim 50\%$ presented the highest volume, mentioning that higher levels of gelatinization may cause severe degradation of the starch molecules, reducing its water entrapment capacity. Consequently, in pellets with low gelatinization, the opening of starch granules could be insufficient, reducing its water retention, being the water less available to use as a vehicle for expansion during microwave heating. In the present work the microwave expanded snacks presented volume values from 2.07 to 6.60 mLg^{-1} , which are in the range of values obtained in the above mentioned work (0.70 to 10.68 mLg^{-1}). However, Case *et al.* (1992) reported in third-generation snacks expanded by deep-fat frying that the snack foods with higher gelatinization (approximately 75%) of the starch showed higher volume. Also, in the present study the high values of specific volume obtained at low FMC levels, could be due to an increase in gelatinization levels under these conditions. Taverna *et al.* (2012) reported that low FMC values in the blends can cause a decrease in their flow velocity within the extruder, extending the residence time, and thus increasing the gelatinization and expansion of the products. Similarly, Ding *et al.* (2005) reported that high moisture contents have a plasticizing effect on starches, as they cause a decrease in the viscosity within the extruder and decrease its expansion. These authors also mention that as the extrusion temperature decreases, the starch gelatinization diminished, and the growth of the bubbles is compressed, resulting in less expanded and denser products. On the other hand, in the Figure 1b is shown the effect of T and DS on the SV of TGS, at constant FMC = 28%. It can be observed that at low T ($< 105 \text{ }^\circ\text{C}$) as DS increased, the SV values tended to decrease. This behavior could be due to the dilution effect, since

with increasing DS, the concentration of starch in the samples decreased, reducing the starch swelling ability. It has been reported in the literature that the addition of starch gives excellent characteristics of expansion values in snack foods (O'Shea *et al.*, 2014). Similarly, the viscoelastic properties could have been affected by the increase in DS levels, since winter squash is high in fiber. According to Van der Sman and Broeze (2013), the fiber presented a higher capacity of water absorption, therefore, could have modified the glass transition temperature of the melt.

It could also have caused a lower volume by adhering to the bubble structure and consequently puncturing the cell and reducing the cell extensibility.

3.3 Moisture of pellets

Because of the extruded pellets normally present low moisture values, they exhibit a great stability during their storage, unlike other cereal products such as bread or cake whose moisture levels are normally high (Asare *et al.*, 2004). In the Figure 2a is shown the effect of DS levels and T on the moisture content of the pellets, at constant FMC = 28%. It can be shown that the highest values of moisture ($> 11.5\%$) were presented at high T ($> 128 \text{ }^\circ\text{C}$) and low DS ($< 6\%$). This variable of response showed a moderate correlation with the T factor ($r = 0.57$, $P = 0.007$). This behavior could be due to that under conditions of high temperatures, a greater gelatinization in the starch structure could have occurred, allowing a greater retention of water in the pellets. According to O'Shea *et al.* (2014), the moisture content of a snack is the driving force for nucleation and bubble expansion, where this parameter is related to the expansion properties such as specific volume, where higher moistures gave a larger expansion. In the present work the highest values of SV were presented under conditions of high T, however, the Pearson correlation between the variables of response moisture of pellets and SV was not significant ($r = 0.35$, $P = 0.11$). Lee *et al.* (2000) reported that the maximum volume of pellets expanded by microwave was obtained at a moisture content of pellets between 10-13%. These authors mention that during microwave heating, in the pellets with low moisture content there was insufficient superheated water for complete expansion, causing low volume values, whereas, high moisture content of pellets hinders the sudden vapor pressure release due to the lack of a pressure barrier diminishing the expansion.

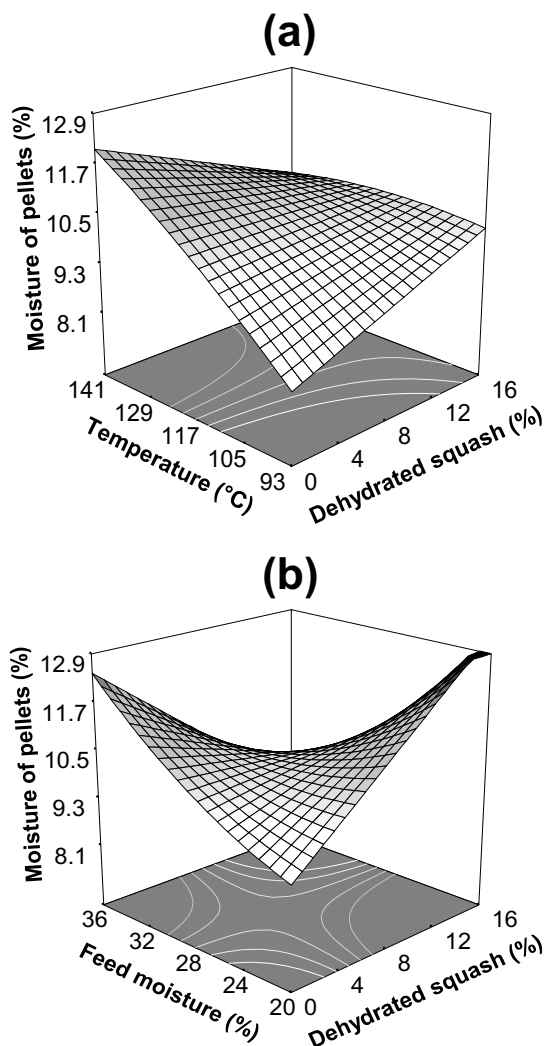


Fig. 2. Effect of the addition of dehydrated squash (DS) and temperature (T) (a, at FMC = 28%), and feed moisture content (FMC) (b, at T = 117 °C), on the moisture of extruded pellets.

The above mentioned results coincide with the results reported in the present study, since the pellets with the highest moisture levels (11-12%) were obtained under conditions of high T (> 129 °C), where the highest values of SV were obtained. Also, the pellets with lower moisture content (< 9.5%) were obtained at low T (< 105 °C), where the lowest SV values were presented. Also, it can be observed that at high T (> 129 °C) as the DS levels were increased, the moisture values of the pellets decreased. This could be due to the fact that, in these conditions, the combination of high temperatures and high DS values decreased the viscosity of the materials in the

extruder, reducing the residence time of the materials in the extruder, presenting less modification in their structures due to a decrease of thermomechanical damage. On the other hand, in the Figure 2b is shown the effect of DS and FMC on the moisture of pellets, at constant T = 117 °C. It can be shown that the highest values of moisture of pellets (> 11.5%) were presented at low FMC (< 24%) and high DS (> 12%). This parameter showed a moderate negative correlation with the FMC factor ($r = -0.54$, $P = 0.01$). This could be due to the fact that, at low FMC, occur high shear rates and residence times, increasing macromolecular starch degradation, achieving greater entrapment of water in the pellets, which could cause high SV values. According to Moraru and Kokini (2003), the expansion of extruded products is a complex phenomenon that usually occurs at high temperatures and low moisture, due to different structural transformations of biopolymers of starch (transition and phase transformations), and nucleation, obtaining the formation of air bubbles. Similarly, the high moisture content in the pellets obtained at low FMC (< 24%) and high DS (> 12%) could have been due to the high dietary fiber content in the dehydrated squash (Delgado-Nieblas *et al.*, 2017b), which could have increased the water retention of the pellets. However, at high DS (> 12%), when FMC levels were increased (> 30%) a drastic decrease in the moisture values of pellets was observed. This may be due, to a plasticizing effect given by the high levels of FMC in combination with dietary fiber and simple sugars contained in winter squash. This could have reduced the viscosity and shear forces in the extruded samples (Nor *et al.*, 2013) resulting in minor modifications of the material structures and reducing the entrapment of water inside the pellets.

3.4 Viscosity profiles

The Figure 3 shows the effects of temperature (T), feed moisture content (FMC) and dehydrated squash levels (DS) on the viscosity profiles of snack foods expanded by microwave. In the Figure 3a is shown the effect of T (at FMC = 28%, DS = 8%) on the viscosity values. It can be seen that at low T (93 °C) was presented a viscosity value of 2027 cP at 92 °C ($V_{92\text{ }^{\circ}\text{C}}$) in the Rapid Visco-analyser (RVA), showing a viscosity profile very similar to materials without thermic processing. This behavior may be due to that under low T conditions, few changes were made in the structure of the components of the mixtures, which allowed higher water absorption during the

RVA analysis, and an increase in the viscosity values was registered. Also, when the T was increased to 141 °C, the value of ($V_{92\text{ }^\circ\text{C}}$) decreased to 1420 cP, which could indicate that the structure of the starch was modified by the severe processing conditions. This behavior coincides with that reported by Carvalho *et al.* (2002) in third-generation snack foods made from blends of wheat flour, rice and banana. These authors reported that at high T the mass becomes more plastic and less viscous, resulting in greater mechanical and thermal damage, resulting in a greater degradation of the starch and, consequently, lower values of viscosity. Also, in the Figure 3b are shown the viscosity values of the extruded products for effect of the FMC factor (at T = 117 °C, DS = 8%). It can

be observed that the treatment with lower FMC (21%) presented the lowest value of $V_{92\text{ }^\circ\text{C}}$, showing a value of 893 cP, as well as relatively high values of viscosity at low heating temperatures in the RVA equipment. This is due to high starch degradation under these conditions, and to the ability of highly gelatinized products to absorb water at low temperatures during the measurement of viscosity in the equipment. Carvalho *et al.* (2002) reported that the utilization of low moisture content and high temperature resulted in an increased mechanical effort during the extrusion process of third-generation snacks, obtaining high starch degradation and low viscosity values. Also, by increasing the FMC to 35%, the values of $V_{92\text{ }^\circ\text{C}}$ increased to 1741 cP.

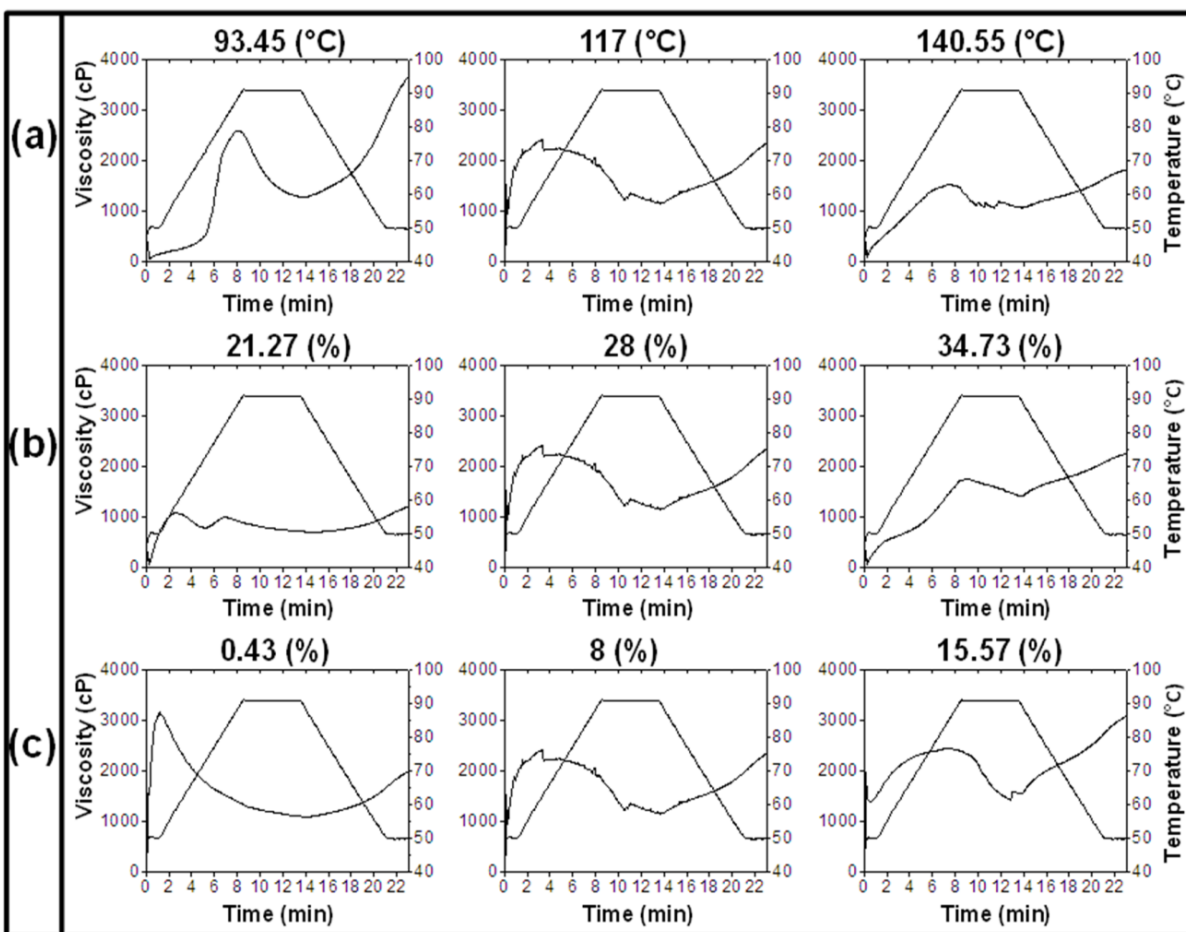


Fig. 3. Effect of temperature (T), at FMC = 28%, and DS = 8% (a); feed moisture content (FMC) at T = 117 °C, and DS = 8% (b); and dehydrated squash (DS), at T = 117 °C, and FMC = 28% (c), on the viscosity profiles of snack foods expanded by microwave heating.

This behavior is similar to that reported by Limón-Valenzuela *et al.* (2017) in third-generation snack foods expanded by microwave heating, made from milk protein concentrate and quality protein maize. These authors found that as the moisture content was > 24%, the viscosity values increased, which was related to low starch degradation in such processing conditions. Similarly, in the Figure 3c is shown the effect of dehydrated squash levels (DS) on the $V_{92\text{ }^\circ\text{C}}$. It can be seen that the treatment with the highest content of DS presented the highest $V_{92\text{ }^\circ\text{C}}$, being 2393 cP. This behavior can be related to the values of $V_{92\text{ }^\circ\text{C}}$ found in the raw materials used for the preparation of the snacks, where the DS presented the highest $V_{92\text{ }^\circ\text{C}}$ value, being 9455 cP, whereas, corn starch and whole yellow-corn flour presented $V_{92\text{ }^\circ\text{C}}$ values of 3385 cP and 2009 cP, respectively.

3.5 Differential scanning calorimetry (DSC)

The Figure 4 shows the effects of temperature (T), feed moisture content (FMC) and addition of dehydrated squash (DS) on the DSC thermograms in snack foods expanded by microwave-heating. It is observed that the treatment obtained at low T (93 °C), at constant FMC = 28% and DS = 8%, had a very low transition enthalpy of 0.034 J/g, presenting an initial gelatinization temperature (T_0) of 68.30 °C, a peak gelatinization temperature (T_p) of 70.11 °C and a final gelatinization temperature (T_f) of 71.87 °C. However, when the T was increased to 117 °C and 141 °C, no gelatinization peaks were presented. This behavior could be due to the severity of the latter treatments that could have damaged some compounds present in the samples, such as the starch, degrading it and causing this polymer to have a gelatinized structure. These results are similar to those found by Aguilar-Palazuelos *et al.* (2006), who reported that in third-generation snack foods at constant moisture content of 23%, as the ET was increased, the enthalpy values decreased from 1.11 J/g until the gelatinization peak disappeared. Case *et al.* (1992) reported in third-generation snacks expanded by deep-fat frying in vegetable oil that as the T was increased, snack foods with higher gelatinization (approximately 75%) of the starch were obtained, which presented higher volume and lower bulk density. The above mentioned coincides with the results of the present work, since in conditions of high T were presented products with higher values of specific volume.

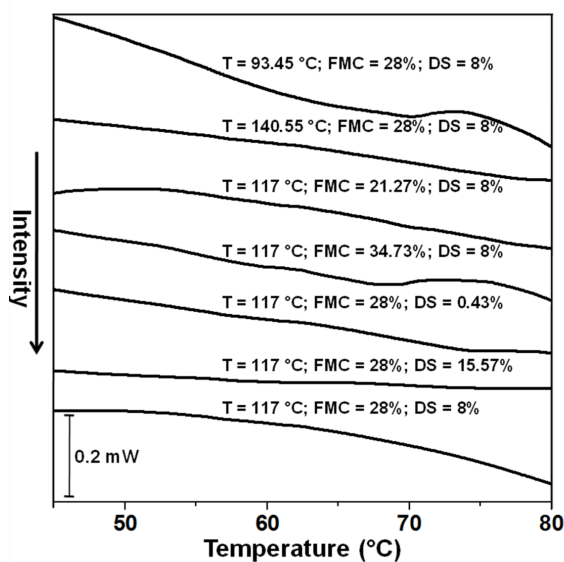


Fig. 4. Effect of temperature (T), feed moisture content (FMC) and dehydrated squash (DS) on the DSC thermograms of snack foods expanded by microwave heating.

Likewise, the results found in the present study are similar to those found by Lee *et al.* (1999) who reported, in extruded products made from corn starch, that materials extruded at $T = 80\text{ }^\circ\text{C}$ had a small gelatinization peak, which disappeared when the samples were processed at T of 90 and 100 °C. On the other hand, when the effect of FMC on the DSC thermograms, at constant $T = 117\text{ }^\circ\text{C}$ and $DS = 8\%$, was analyzed, it was observed that at low and intermediate FMC levels (21 and 28%) was not presented a peak of gelatinization. However, in the treatment obtained at high FMC level (35%) a small gelatinization peak was observed ($T_0 = 66.42\text{ }^\circ\text{C}$, $T_p = 69.02\text{ }^\circ\text{C}$, $T_f = 70.89\text{ }^\circ\text{C}$) with an enthalpy value of 0.124 J/g. As can be observed, there is a slight displacement of the gelatinization peak towards a lower temperature in relation to the treatment obtained at low T (93 °C) with FMC = 28%, which could be due to a decrease in the glass transition temperature (T_g) as a consequence of an increase of the FMC, modifying the thermal behavior of the starch. Robin *et al.* (2011) reported the same behavior in extruded products made from wheat flour, where the T_g of the products decreased when was increased the moisture content. Also, the behavior could be due to that at high FMC, a decrease of the friction inside the extruder could have presented, causing less degradation of the starch and reducing the gelatinization. On the other hand,

the variation of the DS levels, at constant $T = 117\text{ }^{\circ}\text{C}$ and $\text{FMC} = 28\%$, did not produce important changes in the thermograms, since no gelatinization peak was presented in the three different DS levels, which could be due to that in these conditions the products were partially or totally gelatinized. In the thermograms of the raw materials used for the preparation of the snacks, it was found that the corn starch presented an enthalpy value (ΔH) of 12.60 J/g , which is a value close to that reported by Maache-Rezzoug *et al.* (2008), in native corn starch (11.4 J/g). Also, the yellow corn flour had an enthalpy value of 2.7 J/g , which is in the range of values (2.13 to 8.35 J/g) reported by Singh *et al.* (2009) for different corn varieties. On the other hand, the dehydrated squash did not present gelatinization peak, which could be due to the small quantity of starch of this material, or that the samples were partially or totally degraded.

3.6 X-ray diffractograms (XRD)

In the Figure 5a the X-ray diffraction patterns of the raw materials used for the preparation of third generation snacks can be observed. The corn starch had 3 major peaks at 2θ values of 15 , 18 , and 23 ° , which represents a typical type-A-cereal pattern. This pattern is similar to the patterns reported in native maize starch by Diop *et al.* (2011). In addition, yellow-corn flour showed a pattern of X-ray diffraction type A, which is characteristic of cereals, only in this case peaks with lower area in the 2θ values mentioned above were presented. This could be due to the fact that the yellow-corn flour had a previous grinding process, which may have slightly degraded its structure with loss of crystallinity. Moreover, the dehydrated squash presented a pattern of X-ray slightly amorphous, which may be due to a double thermal processes applied on the raw material, firstly during the dehydration step and secondly during the milling process to obtain the flours. In the Figure 5b is shown the X-ray diffraction patterns of the microwave snack foods as affected by the T , FMC , and DS factors. When the effect of T (at $\text{FMC} = 28\%$, $\text{DS} = 8\%$) was analyzed, it can be observed that the three treatments obtained at different T presented damage in their crystalline structure as a consequence of the extrusion process, presenting main peaks at 2θ values of 19.5 ° and 20.5 ° .

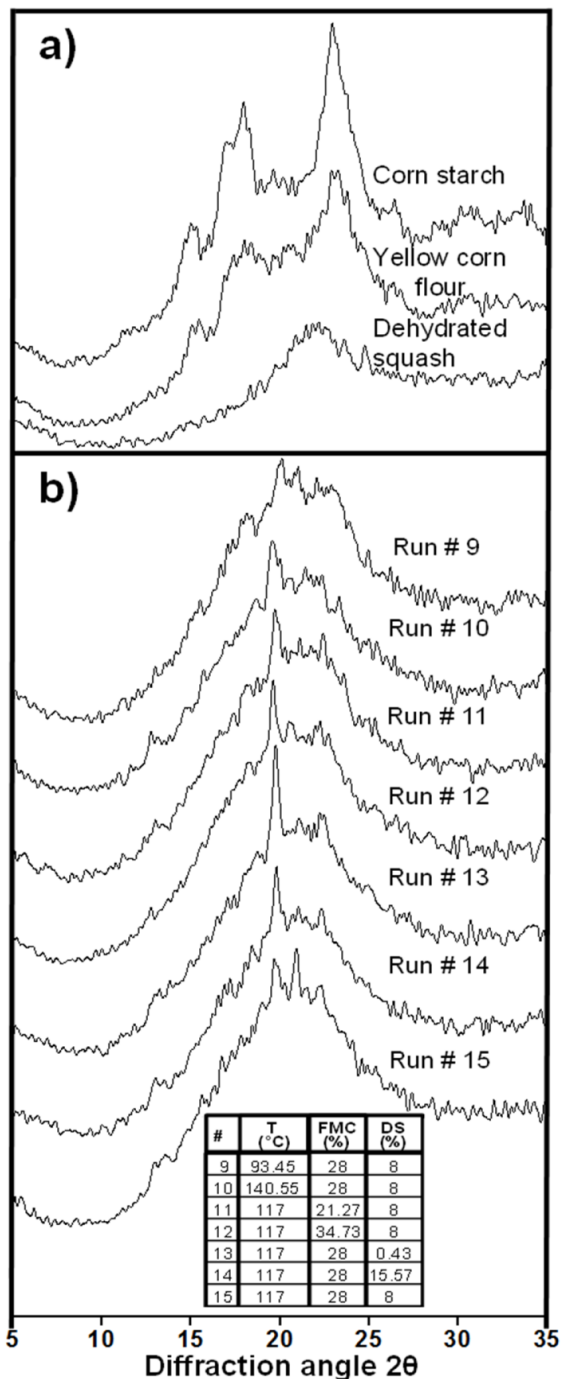


Fig. 5. Effect of temperature (T), feed moisture content (FMC) and dehydrated squash (DS) on the x-ray diffraction patterns of the raw materials (a) and third generation snack foods (b).

These peaks may be due to the formation of complexes between retrograded amylose and free fatty acids present in the samples (type V X-ray diffraction pattern), which is characterized by a peak at 2θ values of $\approx 20.0^\circ$, as suggested by De Pilli *et al.* (2008). It can be observed that the treatment obtained at low T (93°C) (Run 9) showed peaks with a larger area, which may be evidence of a lower thermal damage in the starch structure as a consequence of the extrusion process. Also, in this treatment an additional peak is observed at a 2θ value of 18° . This peak represents a type A X-ray diffraction pattern, characteristic of cereal starches, which disappeared when T of 117°C (Run 15) and 141°C (Run 10) were used. Chung and Liu (2009) mentioned that the crystallinity of the starch samples may be affected by the severity of the processes, since in treatments not very severe, the part of the sample that suffers the most damage is the amorphous region, not showing important changes in the crystalline region (amylopectin chain).

However, when the sample is exposed to treatments with greater severity, a high degradation of the crystalline and amorphous region of the starch occurs, causing damage to the structure of the amylopectin. Also, the effect of FMC (at T = 117°C , DS = 8%) on the X-ray diffraction patterns can be seen in the same figure. The three treatments presented peaks at 2 values of approximately 20° , characteristic of an X-ray diffraction pattern type V. Similarly, it can be observed that the treatment obtained at high FMC level (34%) (Run 12) presented a slightly higher peak at 2θ values of approximately 20° . This could be due to less thermomechanical damage in the structure of the starch by the lubricating effect of the water, allowing the samples to flow more quickly inside the extruder. Similarly, the effect of the DS (at T = 117°C , FMC = 28%) on X-ray diffraction patterns can be seen in the Figure 5b.

For the three treatments, the peaks can be observed at 2θ values of $\sim 20^\circ$. As mentioned above, these peaks correspond to a type V X-ray diffraction pattern. However, in the treatment obtained at low DS (0.43%) (Run 13) a larger area in the peak was obtained at a value 2θ of $\sim 20^\circ$, in relation to intermediate (Run 15) and high (Run 14) DS levels. This behavior may have been due to a great level of starch in these conditions, which was supplied by the raw materials corn starch and yellow corn flour, which may have caused an increase in the amylose content, allowing a greater formation of amylose-lipid complexes.

3.7 Color parameters

The color of foods is an important parameter as it may indicate changes in food quality due to processing, storage, and other factors. Furthermore, it is also an important sensory attribute of food products (Aziah and Komathi 2009). The Hue angle (h^*) is considered a qualitative attribute of color, and it is used to define the difference of a certain color with reference to gray color with the same lightness. An angle of 0° or 360° represents red Hue, whilst angles of 90° , 180° and 270° represent yellow, green and blue Hues, respectively.

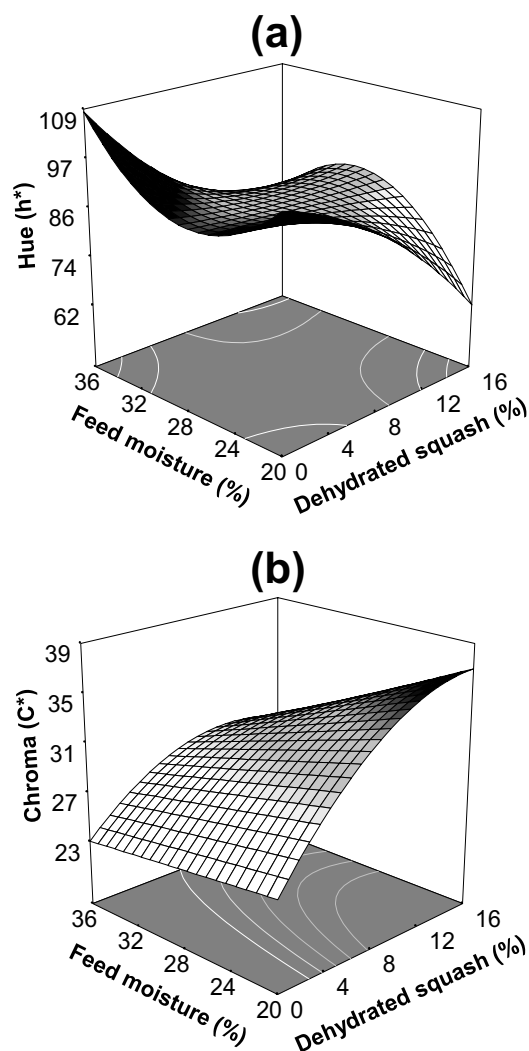


Fig. 6. Effect of the addition of dehydrated squash (DS) and feed moisture content (FMC) on the color parameters hue (a) and chroma (b) of extruded third generation snack foods, at T = 117°C .

Also, Chroma (C^*) indicates saturation, being used to determine the degree of difference of Hue in comparison to a gray color with the same lightness. The higher the Chroma values, the higher the color intensity of samples perceived by humans (Pathare *et al.*, 2013). The Figure 6a shows the effects of FMC and DS on Hue values (color tonality) at constant $T = 117^\circ\text{C}$. The Hue values of snack foods ranged from 82.1 to 89.8. As pure yellow has a Hue value of 90, this reflects that the snacks presented a yellowish color. It can be observed that the lowest values (< 83) for this variable of response were presented under conditions of high DS ($> 12\%$) and low FM ($< 24\%$). This parameter had a negative correlation with the DS study factor ($r = -0.78$, $P = 0.001$). This behavior could be due to the yellow-reddish coloration present in winter squash flour, due to the high presence of carotenoids (Jacobo-Valenzuela *et al.*, 2011), which caused a decrease in Hue values. Similarly, the decrease in Hue values at low FMC could be due to the high friction inside the extruder under these conditions, which may have generated non-enzymatic darkening reactions (Maillard reactions), obtaining darker snacks (Nayak *et al.*, 2011). Also, at high levels of DS ($> 12\%$) as FMC levels were increased, the Hue values decreased. This could be due to a lower severity of the extrusion process, since the materials could have presented greater fluidity inside the extruder, presenting less thermomechanical damage, with less darkening. On the other hand, the Figure 6b shows the effects of FMC and DS on the Chroma values (color intensity) of snacks at constant $T = 117^\circ\text{C}$, presenting these products Chroma values from 25 to 36. In the present study, the Chroma values presented a positive correlation with the study factor DS ($r = 0.76$, $P = 0.003$), since by increasing the DS levels was shown an increase in Chroma values. This may be due to the intense yellow color of the winter squash, due to the presence of carotenoids. On the other hand, this variable of response showed a negative correlation with Hue values ($r = -0.75$, $P = 0.008$). This coincides with that reported by Henriques *et al.* (2012) and Guiné and Barroca (2012) in dried pumpkin (*Cucurbita maxima* L.), who reported that the dried pumpkins with lower Chroma values had the highest values of Hue.

3.8 Sensory study

The results for the test of general acceptability of third generation snacks are shown in the Figure 7. In this study the sensory acceptability of three

different products was compared. A product (SP) was composed by the blend corn starch:whole yellow-corn flour, added with dehydrated squash, which was obtained under conditions of $T = 131^\circ\text{C}$, $\text{FMC} = 24\%$ and $\text{DS} = 12.5\%$. Another product was a control (CP) obtained under the same conditions of T and FMC mentioned above, but which was only composed of corn starch:whole yellow-corn flour, without dehydrated squash, while the third product was a commercial third generation snack food (CMP). In terms of general acceptability, the results of sensory analysis for the SP showed that approximately 79% of the panelists indicated a degree of acceptance ≥ 5 , while about 21% said they disliked the product. Likewise, the acceptability results for the CP indicated that most of the panelists ($\sim 66\%$) mentioned a degree of acceptance ≥ 5 , while about 34% said they disliked the product. In the CMP evaluation, the results showed that 85% of people selected values from the hedonic scale ≥ 5 , while 15% of the evaluators mentioned that they did not like the snack.

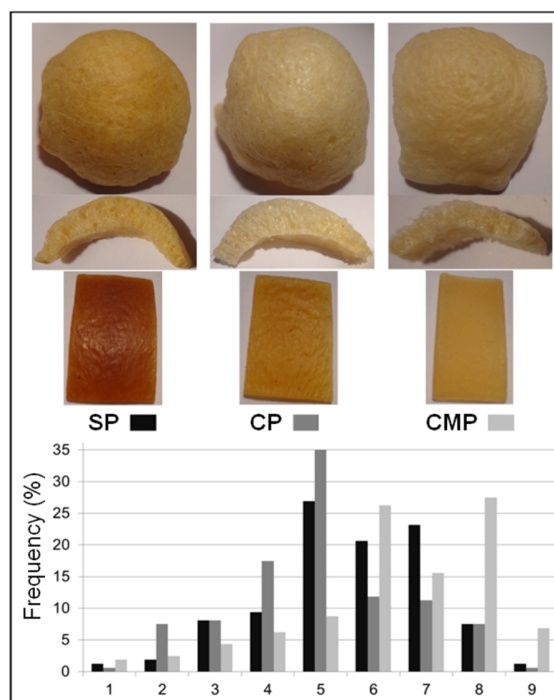


Fig. 7. Frequency analysis of the general acceptability test (1 = dislike extremely; 2 = dislike very much; 3 = dislike moderately; 4 = dislike slightly; 5 = neither like nor dislike; 6 = like slightly; 7 = like moderately; 8 = like very much; 9 = like extremely) in sensory study of snack foods (SP = squash product; CP = control product; CMP = commercial product).

The mean comparison results indicated that a significant statistical difference ($P < 0.05$) was found between the three products, with the highest acceptability of the CMP. Likewise, when the sensory acceptability of the snacks by genders in all three products was compared, it was found that there was no significant difference ($P > 0.05$) in snack acceptability between men and women. Similarly, when the general acceptability of the snacks was compared, among people who received the nutritional information of the snacks, regarding the people who did not know the information, it was found that there was no statistically significant difference ($P > 0.05$). In the analysis by attributes using the Just About Right (JAR) scale, it was found that the SP presented the best acceptance for the color parameter, since 47.5% of evaluators chose the value “just about right”, showing a significant difference ($P < 0.05$) with respect to the other two products, whereas no significant difference was found between CP (35%) and CMP (36.2%). This could have been due to the pigments provided by the squash, which caused a more attractive coloration as judged by the evaluators. It has been reported (Delgado-Nieblas *et al.*, 2017a) in foods obtained by extrusion, that the addition of materials that exhibit yellow-orange coloration improves their acceptability in color parameters. Also, in the flavor analysis, a significant difference between the three products was presented for the value “just about right”, with the CMP having the best acceptance (33.1%), followed by SP (30.6%), whereas the lower acceptance was showed by the CP (26.2%). Regarding the purchase intention by the evaluators, the higher purchase intention was presented by the CMP, since 72.8% of evaluators selected the options 1 = will buy, 2 = probably will buy, or 3 = maybe buy, followed by SP (53.4%), and with less purchase intention the CP (36.5%). This could be due to the fact that some additives could have been added in the production of commercial third generation snack foods (CMP), increasing their acceptability. However, the snack foods added with dehydrated squash (SP) presented greater acceptability than the control (CP) in terms of flavor and purchase intention. This is positive, since in addition to having a relatively high sensory acceptability, these snacks may possess a better nutritional content due to the important levels of carotenoids, dietary fiber and phenolic compounds provided by squash (Jacobo-Valenzuela *et al.*, 2011).

Conclusions

The second-order polynomial model used in the present study was adequate for data analysis, showing values of $R_{adj}^2 \geq 0.72$, P of $F < 0.001$, and none of the responses showed lack of fit ($P > 0.05$). The higher values of specific volume and moisture of pellets were presented at high T and low FMC, while the lower Hue values and the higher Chroma values were obtained at high DS levels. The microstructural changes in the third generation snacks were mainly related to modifications in starch structure. The test of general acceptance in the sensory study indicated that the snack foods added with DS were accepted by a high percentage of evaluators ($\sim 79\%$). Furthermore, the evaluation by attributes showed that the snacks added with dehydrated squash, presented acceptable features of color and flavor. The results of the present study indicate that the extrusion process can be used to produce third generation snack foods with acceptable physical and sensory properties, by adding dehydrated squash and yellow corn. The consumption of these snacks could present potential benefits in human health due to the important content of bioactive compounds provided by these foods, as previously reported.

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Abbreviations

%	percentage
°C	degree celsius
Å	ångström
CMP	commercial product
cP	centipoise
CP	control product
cv	cultivar name

FMC	Feed moisture content
DS	dehydrated squash content
DSC	differential scanning calorimetry
g	grams
h	hours
J	Joule
kV	kilovoltage
mA	milliamperes
min	minutes
mL	milliliters
mm	millimeters
RVA	rapid visco analyser
SF	snack foods
SP	squash product
SV	specific volume
T	temperature
μm	micrometers

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