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ABSTRACT
Extruded third-generation snack foods (TGS) can be produced adding materials rich in bioactive compounds, such as the bagasse of naranjita fruit (Citrus mitis B.). The aim of this work was to study the effect of extrusion temperature (ET; 89.8–140.2°C), moisture content (MC; 21.10–32.89%) and dehydrated naranjita bagasse (DNB) content (1.12–11.88%) on TGS properties, such as, carotenoids content, physical and sensory characteristics. For data analysis, response surface methodology was used. The highest expansion index and the lowest penetration force were presented at high ET and low MC, whereas the highest carotenoids content and ΔE were presented at high DNB. Also, the highest sensory acceptability was presented combining high ET and MC, and low DNB. The optimal processing conditions were ET = 125°C, MC = 23% and DNB = 8.03%. TGS with acceptable physical and sensory properties, in addition to important carotenoid levels, were obtained.

Introduction

The extrusion technology is a food-processing operation that uses high temperatures, short times (HTST) and high shear forces, producing foods with different physical and chemical characteristics (Awolu, Oluwafenamni, Fafowora, & Oseyemi, 2015). This technology allows the development of a wide variety of food products, such as snack foods, highlighting the third-generation snack foods (TGS), also called pellets or half products. These TGS are not ready to eat, and therefore an expansion process is required before being consumed, which can be performed through different processes such as deep-fat frying, hot-air puffing, baking, infrared and more recently microwave heating (Moraru & Kokini, 2003). The TGS are highly consumed because of their low cost and easy preparation, being elaborated mainly from corn or potato starch (St-Onge et al., 2007), and so these are regarded as low nutritional contribution foods. In recent years, the interest of consumers for nutritious foods has increased that provide compounds with health benefits (Brennan, Derbyshire, Tiwari, & Brennan, 2013). Thus, it is important to elaborate such foods, adding fruits, vegetables and grains with high bioactive compounds content, improving their nutritional/nutraceutical properties. Therefore, addition of some pigmented corn varieties, such as yellow corn, has been suggested. This cereal contains secondary metabolites such as phenolic compounds and carotenoids, whose consumption could have potential health benefits (Žilić, Serpen, Akkiloglu, Gökmem, & Vančetović, 2012). Zielinski, Kozlowska, and Lewczuk (2001) reported that the extrusion process increased the content of phenolic compounds and antioxidant activity in cereals. This behavior was related to the release of phenolic acids by the extrusion process. The same behavior was reported by Stojcska, Ainsworth, Plunkett, Ibanoglu, and Ibanoglu (2008) in...
expanded snacks added with cauliflower by-products. Also, the use of whole-grain yellow corn in food production may increase the levels of dietary fiber in the foods produced from this grain. Similarly, the utilization of some citrus by-products has been suggested for the elaboration of TGS that are not being exploited and pollute the environment. Among these products, the fruit of naranjita (Citrus mitis B.) is a highlight. This fruit, also known as calamondin or calamansi in Asian countries (Lou, Hsieh, Ho, Ferng, & Chang, 2015), is highly produced in the northwest of Mexico, being consumed in fresh or processed form, such as jellies and drinks. The naranjita juice industry generates by-products (bagasse) that are generally wasted, despite having an excellent content of bioactive compounds (mainly dietary fiber, carotenoids and flavonoids) (Delgado-Nieblas et al., 2015). In addition, studies have reported that citrus peel (by-products) has antioxidant, antitumor and antimicrobial properties due to its flavonoid content (Yu, Lou, Chiu, & Ho, 2013). The response surface methodology (RSM) is a tool commonly used for data analysis in the processing of foods rich in bioactive compounds (Saikia, Mahnot, & Mahanta, 2015), which uses mathematical and statistical techniques that are useful for modeling and analysis of problems in which a dependent response is influenced by several variables with the objective to optimize the response (Montgomery, 2001). RSM can permit the obtaining of optimum processing conditions in the elaboration of extruded products by analyzing different properties to produce a quality food. Additionally, the scientific information on the effect of the addition of citrus by-products in different properties of snack foods produced by extrusion is scarce. Therefore, the objective of the present paper was to study the effect of extrusion process on the carotenoid content, physical and sensory properties of TGS added with bagasse of naranjita fruit.

Materials and methods

Raw materials

The raw materials used in this research were whole-grain yellow-corn (Zea mays L.) and naranjita fruit (Citrus mitis B.). Both materials were obtained from the local market in Culiacan, Mexico. The juice of naranjita fruit was extracted and the seeds were discarded, leaving the by-products (peel and segment walls) in a fresh state. After that, the dehydrated naranjita bagasse (DNB) was obtained following the optimized process described by Delgado-Nieblas et al. (2015), with some modifications. Both materials, whole-grain yellow-corn and DNB, were ground in a hammer mill (Pulvex model 200, Mexico City, Mexico) and sieved to obtain products with a particle size ≤420 μm. Also, commercial corn starch was used (IMSA, S.A. de C.V., Guadalajara, Mexico). The raw material content for the elaboration of the TGS was obtained through a preliminary study, using a ratio of corn-starch:whole-grain yellow corn flour (60:40), whereas the content of DNB varied from 1.12% to 11.88%, according to the experimental design (Table 1).

Extrusion process

The TGS were elaborated by extrusion using a laboratory extruder (Brabender 20DN, model 8–235-00, O HG Brabender, Duisburg, Germany), with three heating zones. The mixing/cooking zone temperature varied according to the experimental design from 89.9°C to 140.2°C, whereas the temperatures of the feeding and die zones were kept constant at 75°C. An extrusion screw (compression ratio 1:1) at a speed of 75 rpm and a rectangular die (aperture: 20 mm wide, 1.0 mm high, 100 mm long) were used. The obtained pellets were cut into pieces of 3 cm long and dried in a room with ventilation and controlled temperature (~ 25 ± 2°C) during three days or until a MC of 8–12% (method 925.03 Association of Official Analytical Chemists [AOAC], 2012), wrapped in sealed plastic bags, and stored under refrigeration conditions (4–6°C) until its analysis.

Proximal composition

The proximal composition of raw materials and the TGS obtained at optimal extrusion conditions was analyzed according to the methodology reported by AOAC (2012) for protein (960.52), fat (920.39), ash (923.03), moisture (925.10) and crude fiber (962.09).

Expansion index (EI)

This determination was performed using the seed displacement method, according to the methodology described by the AACC International Approved Method 10–05.01 (2010). The values of EI were calculated knowing the specific

| Assay | $X_1$ | $X_2$ | $X_3$ | ET (°C) | MC (%) | DNB (%) |
|-------|-------|-------|-------|--------|--------|---------|
| 1     | −1    | −1    | −1    | 100    | 23.5   | 3.3     |
| 2     | −1    | 1     | −1    | 130    | 23.5   | 3.3     |
| 3     | 1     | −1    | −1    | 100    | 30.5   | 3.3     |
| 4     | 1     | 1     | −1    | 130    | 30.5   | 3.3     |
| 5     | −1    | −1    | 1     | 100    | 23.5   | 9.7     |
| 6     | 1     | −1    | 1     | 130    | 23.5   | 9.7     |
| 7     | −1    | 1     | 1     | 100    | 30.5   | 9.7     |
| 8     | 1     | 1     | 1     | 130    | 30.5   | 9.7     |
| 9     | −1.682| 0     | 0     | 89.77  | 27     | 6.5     |
| 10    | 1.682 | 0     | 0     | 140.23 | 27     | 6.5     |
| 11    | 0     | −1.682| 0     | 115    | 21.11  | 6.5     |
| 12    | 0     | 1.682 | 0     | 115    | 32.89  | 6.5     |
| 13    | 0     | 0     | −1.682| 115    | 27     | 1.12    |
| 14    | 0     | 0     | 1.682 | 115    | 27     | 11.88   |
| 15    | 0     | 0     | 0     | 115    | 27     | 6.5     |
| 16    | 0     | 0     | 0     | 115    | 27     | 6.5     |
| 17    | 0     | 0     | 0     | 115    | 27     | 6.5     |
| 18    | 0     | 0     | 0     | 115    | 27     | 6.5     |
| 19    | 0     | 0     | 0     | 115    | 27     | 6.5     |
| 20    | 0     | 0     | 0     | 115    | 27     | 6.5     |

$ET = extrusion
temperature; MC = moisture content; DNB = dehydrated naranjita bagasse.

$ET = temperatura de extrusión; MC = contenido de humedad; DNB = contenido de bagazo deshidratado de naranjita.
volume of expanded and nonexpanded pellets, using the following equation:

$$EI = \frac{V_{ep} - V_{nep}}{V_{nep}}$$

where $V_{ep}$ = volume of expanded pellet and $V_{nep}$ = volume of nonexpanded pellet. A total of 30 replicates were performed per treatment.

Penetration force (PF)

The PF in TGS expanded by microwave heating was measured with a texturometer (3342, Instron, Norwood, MA, USA), registering the force (N) required to penetrate the product. The extruded samples were penetrated using a cylindrical flat-end plunger of 1.5 mm diameter. A cell of 500 N, a penetration depth of 1.5 mm and a speed of 0.55 mm/s were used. For each treatment, 50 replicates were performed (one snack for measurement) and the average of all the determinations was reported.

Total color difference ($\Delta E$)

A tristimulus colorimeter (CR-210, Minolta, Tokyo, Japan) was used to measure color in the TGS. The samples of expanded products of the different treatments were grinded (Anton, Fulcher, & Arntfield, 2009) to a particle size less than 250 µm, and they were placed in petri dishes of 14 cm diameter. Four equally spaced readings were taken, and the mean values of $L^*$, $a^*$ and $b^*$ were reported. To calculate $\Delta E$, the values of $\Delta L^*$, $\Delta a^*$ and $\Delta b^*$ were used, which indicate the difference between the color parameters of the processed samples and those of the unprocessed mixtures, being obtained by the following equation:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

Total carotenoids (TC)

The determination of TC content was carried out according to the methodology of AOAC (2012), method 970.64, using a spectrophotometer Model 10, UV GENESYS, Series 2H7G229001, Madison, USA. The TC were extracted from TGS expanded by microwave oven grinded to a particle size ≤250 µm, using in the extraction process a solution of HEAT (hexane, ethanol, acetone and toluene, 10:6:7:7 v/v/v/v). A calibration curve was carried out using β-carotene (Sigma-Aldrich Co., St. Louis, MO, USA) by measuring the absorbance at 450 nm. Three repetitions per each treatment were performed and the results were reported as µg/g db.

Sensory acceptability (SA)

The sensory evaluation of TGS expanded by microwave oven was performed by 30 non-trained panelists (Sacchetti, Pinnavia, Guidolin, & Dalla Rosa, 2004) older than 18 years (both genders), who like to consume this type of products. They assessed the overall acceptability in the samples of different treatments of the experimental design and treatment obtained at optimal conditions, based on flavor and texture attributes. The evaluation was done at room temperature (25 ± 2°C) in normal illumination conditions. A 100-mm bidirectional Labeled Affective Magnitude (LAM) scale was used, with a verbal description, ranging from −100 (Greatest Imaginable Dislike) to +100 (Greatest Imaginable Like) in which the value 0 = Neither Like nor Dislike, according to Cardello and Schutz (2004). At the end of each evaluation sheet, a section of observations was added, where each panelist could leave comments on each treatment.

Experimental design

A central composite rotatable experimental design with a value $\alpha = 1.682$ (Table 1) was used, extrusion temperature (ET), moisture content (MC) and DNB being the study factors, with five levels for each one (Box & Behrken, 1960), using the following generic quadratic model:

$$Y_i = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_11X_1^2 + b_22X_2^2 + b_33X_3^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3$$

where $Y_i$ is a generic response, $X_1$ is ET, $X_2$ is the MC, $X_3$ is DNB and $b_0$, $b_1$, $b_2$, $b_3$, $b_{11}$, $b_{22}$, $b_{33}$, $b_{12}$, $b_{13}$ and $b_{23}$ are regression coefficients. The data analysis and optimization were performed with the statistical software Design Expert (version 7.1.6, Stat-Ease, Minneapolis, MN, USA), whereas the Pearson correlations were performed using Statistica 7.0 software (Statsoft, Tulsa, OK, USA).

Optimization

The optimization process was performed using the numerical method with the Design-Expert software (Stat-Ease, Inc., Minneapolis, MN, USA). The variables of response used to optimize were EI, PF, TC and SA. The objective of the optimization was to find the best processing conditions to obtain the highest values of EI, TC and SA, and the lowest values of PF. The criteria for carrying out the optimization process using the responses mentioned above were obtaining of values of EI ≥ 4.5 (reported in commercial TGS), and values of TC ≥ 43.86 µg β-carotene/g db, which were reported by Delgado-Nieblas et al. (2012) for TGS added with winter squash flours. Also, the maximum tolerable value of PF was 8.89 N, which was reported in the previously mentioned work, whereas the minimum tolerable value for SA was 60, which is found in the range of values of LAM scale 55.62 = like slightly and 68.12 = like moderately. This information was used for evaluating the desirability function, which is one of the most widely used technique for process optimization with multiple responses in food industry, varying the desirability from 0 (lowest) to 1 (highest), according to Myers and Montgomery (1995). Two experimental assays were carried out with the optimal conditions and, EI, PF, TC and SA were evaluated. The experimental values were compared with predicted values in order to validate the model obtained.

Results and discussion

Proximal composition

The proximal composition of the DNB, whole-grain yellow corn flour (WYCF) and the TGS obtained under optimum processing conditions was as follows. The DNB presented a value of moisture = 12.23 ± 0.06%, proteins = 10.96 ± 0.36%, lipids = 1.30 ± 0.06%, crude fiber = 8.18 ± 1.02%,
ashes = 4.06 ± 0.30% and carbohydrates = 75.5%. The values presented in DNB were similar to those reported by Delgado-Nieblas et al. (2015) in DNB obtained with hot-air drying. Also, the WYCF showed a value of moisture = 9.37 ± 0.17%, proteins = 8.09 ± 0.45%, lipids = 5.17 ± 0.03%, crude fiber = 1.24 ± 0.25%, ashes = 1.61 ± 0.01% and carbohydrates = 83.89%. The results found in WYCF are close to those reported by Ejíguí, Savoie, Marin, and Desrosiers (2005) in yellow corn. Similarly, the TGS presented a value of moisture = 1.65 ± 0.04%, proteins = 2.76 ± 0.001%, lipids = 1.58 ± 0.12%, crude fiber = 5.38 ± 0.15%, ashes = 1.11 ± 0.03% and carbohydrates = 89.17%. The values obtained in TGS are slightly lower (except ashes) than those reported by Tovar-Jiménez et al. (2015) for TGS expanded by microwave, elaborated with potato starch, nixtamalized corn flour and flours from orange vesicles. The difference in the proximal composition between both works could be due to the different raw materials and processing conditions used for the elaboration of the TGS.

Regression coefficients and statistical analysis

The regression coefficients and analysis of variance for the analyzed responses are shown in Table 2. The independent and dependent variables fitted to a second-order model. All the evaluated parameters showed a significant model ($p < 0.001$), with values of $R^2 \geq 0.67$ and coefficients of variation between 4.41 and 27.79. Most of the parameters did not show lack of fit, except for TC and EI. The statistical analysis (Table 2) indicated that the ET was the factor that showed the more highly significant effect ($p < 0.05$) in the linear and quadratic terms on EI and PF. The factor DNB exhibited a significant effect ($p < 0.05$) in its linear and quadratic terms on TC and SA. On the other hand, MC showed significant ($p < 0.05$) effect in its linear term on EI and ΔE. Also, the interaction ET * MC had significant effect on the variables of response EI, PF and SA, while the interaction ET * DNB had significant effect on PF ($p < 0.05$).

Expansion index (EI)

The EI is one of the main physical parameters of quality for TGS, for which high values are preferred. The effect of ET and MC on the EI of TGS at constant DNB = 6.5% is shown in Figure 1(a). It can be observed that at low MC, when ET was increased, the EI values tend to increase, whereas, at high MC, no significant changes were observed in the EI values by increasing the ET. The highest values of EI ($>7$) were presented by combining ET (>128°C) and MC (<24%). In the present study this response showed a moderate correlation with the ET factor ($r = 0.66$, $p = 0.003$). This behavior could be due to an improvement of the viscoelastic properties of pellets. In addition, low MC permit high shear rates and residence times, increasing starch degradation and expansion. The final structure of expanded TGS is based on the transition of the amorphous matrix. The expansion of extruded products is a complex phenomenon that usually occurs at high ET and low MC, due to different structural transformations (transitions and phase transformations) of

| Table 2. Analysis of variance, regression coefficients, and predicted/true values in the optimization for the studied responses in TGS expanded by microwave. Tabla 2. Análisis de varianza, coeficientes de regresión, y valores predichos/reales en la optimización para las respuestas estudiadas en alimentos BTG expandidos por microondas. |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                                | EI              | PF              | ΔE              | TC              | SA              |
| Intercept                       |                | -136.49         | 140.02          | 40.24           | 47.44           | -355.43         |
| Linear                          | ET              | 1.80            | -1.88           | -               | -               | 3.76            |
|                                | (<0.001)        | (<0.001)        | (<0.001)        | (<0.001)        | (<0.001)        | (0.686)         |
|                                | MC              | 2.74            | -1.90           | -0.946          | -               | 14.42           |
|                                | (0.003)         | (0.24)          | (<0.001)        | (<0.001)        | (<0.001)        | (0.236)         |
|                                | DNB             | -0.23           | 2.69            | 0.926           | -6.39           | -4.13           |
|                                | (0.044)         | (0.011)         | (<0.001)        | (<0.001)        | (<0.001)        | (<0.001)        |
| Quadratic                       | ET              | -4.10           | 6.16E-003       | -               | -               | -0.01           |
|                                | (<0.014)        | (<0.001)        | (<0.001)        | (<0.001)        | (<0.001)        | (0.001)         |
|                                | MC              | -               | -               | -               | -               | -0.19           |
|                                | (<0.003)        | (<0.003)        | (<0.003)        | (<0.003)        | (<0.003)        | (0.003)         |
|                                | DNB             | -               | -               | 1.15            | -               | -0.43           |
|                                | (<0.017)        | (<0.001)        | (<0.001)        | (<0.001)        | (<0.001)        | (<0.001)        |
| Interactions                    | ET*M C          | -0.03           | 0.016           | -               | -               | -0.038          |
|                                | (0.006)         | (0.034)         | (<0.001)        | (<0.001)        | (<0.001)        | (0.032)         |
|                                | ET*D N B        | -               | -0.02           | -               | -               | -               |
|                                | (<0.013)        | (<0.013)        | (0.013)         | (0.013)         | (0.013)         | (0.013)         |
|                                | MC*D N B        | -               | -               | -               | -               | -               |
|                                | ET*M C* D N B   | -               | -               | -               | -               | -               |
|                                | $R^2_{adj}$     | 0.79            | 0.91            | 0.72            | 0.67            | 0.87            |
|                                | CV (%)          | 24.78           | 16.2            | 11.03           | 27.79           | 4.41            |
|                                | $p$ of $F_{model}$ | <0.001         | <0.001          | <0.001          | <0.001          | <0.001          |
| Lack of fit                    | 0.008           | 0.899           | 0.961           | 0.001           | 0.110           |
| Optimization                   | Predicted values | 8.27 ± 1.25     | 2.8 ± 0.88      | -               | 68.59 ± 10.19   | 55.02 ± 2.48    |
|                                | True values     | 8.75 ± 0.28     | 2.7 ± 0.18      | -               | 70.1 ± 2.4      | 60.31 ± 2.3     |

ET = extrusion temperature; MC = moisture content; DBN = dehydrated naranjita bagasse; EI = expansion index; PF = penetration force (N); ΔE = total color difference; TC = total carotenoids (µg/g); SA = sensory acceptability.

ET = temperatura de extrusión; MC = contenido de humedad; DBN = contenido de bagazo deshidratado de naranjita; EI = índice de expansión; PF = fuerza de penetración (N); ΔE = diferencia total de color; TC = carotenoides totales (µg/g); SA = aceptabilidad sensorial.
starch biopolymers, and nucleation, obtaining the formation of air bubbles (Moraru & Kokini, 2003). Tovar-Jiménez et al. (2015) reported in TGS added with orange vesicles, that the highest values of EI were obtained by combining high ET (143°C) and low MC (22%). Also, Camacho-Hernández et al. (2014) reported similar behavior in TGS added with blue corn, expanded by microwave heating, obtaining the highest values of EI by combining ET of 120–125°C and low MC (~ 20%). Lee, Lim, Lim and Lim (2000) reported that the degree of starch gelatinization and the MC of the pellets are the factors that determine the shape, bulk density and expansion of the TGS, suggesting percentages of gelatinization of ~ 50% to obtain high EI values. These authors mention that higher percentages of gelatinization may cause severe degradation of the starch molecules, reducing its size, stability and water-binding capacity, and lowering the EI of products. Also, in the same work is reported that the pellets that have low levels of gelatinization, the opening of starch granules could be insufficient, reducing its ability to absorb water. Therefore, the water would be less available for use as a vehicle for expansion during microwave heating. Moreover, in the present work, the interaction of the content of DNB, with ET and MC factors, did not show significant effect ($p > 0.05$). However, a tendency to decrease the values of EI by increasing DNB was observed (Figure 2). This behavior could be due to the high content of dietary fiber of DNB (44.65 ± 0.70%) (Delgado-Nieblas et al., 2015), which can cause cell wall collapse during the formation of air bubbles. According to Lue, Hsieh, and Huff (1991), this collapse can reduce the ability to retain air inside of the cell walls, and hence decrease the expansion of products.

**Penetration force (PF)**

The PF indicates the resistance of the expanded product to be penetrated and can be correlated with the hardness of the product (Yağıçi & Göğüş, 2009). Figure 1(b) shows the effect of ET and MC on the PF of TGS at a constant level of DNB = 6.5%. It can be observed that the highest values of PF (>11 N) were obtained when low ET levels (<100°C) were combined with levels of MC within the range from 21% to 28%, presenting this response an inverse correlation with EI ($r = -0.68$, $p = 0.002$). This behavior could be due to the fact that in the above conditions TGS with low values of EI were obtained, which presented a higher resistance to penetration, and thus showed higher values of PF. Pérez et al. (2008) reported that the PF is negatively correlated with EI, while this response is positively correlated with the bulk density in TGS and other extruded products. Also, the lower values of PF (<5 N) were obtained at high levels of ET (>115°C) all over the range of MC, which agrees with the information reported by Moraru and Kokini (2003). These authors reported that in extruded products, high values of EI and low values of PF are produced at high ET, as a result of various events such as structural transformations of biopolymers, phase transitions and nucleation, swelling, and growth and collapse of air bubbles. On the other hand, in Figure 3 the effect of ET and DNB on the PF of TGS at MC constant = 27% is shown. The lowest values of PF (<4 N) were obtained at high ET (>115°C) throughout the range of DNB. This behavior could be due to the fact that high ET could have modified the structure of starch, allowing more water entrapment in the pellets, which may have been used as a vehicle for expansion during microwave heating (Delgado-Nieblas et al., 2012). Also, when the ET was increased, the viscoelastic properties of the pellets may have been improved, generating a sufficient vapor pressure for adequate expansion of the pellets. This could have caused the formation of a lot of air bubbles, increasing the pressure and breaking the cell walls, allowing thus the escape of water vapor, expanding the pellets and decreasing the PF (Moraru & Kokini, 2003). On the other hand, the highest values of PF (>11 N) were presented at low ET (<100°C) and high DNB (>6.5%). This could be due to a dilution effect caused by the increase of DNB in the mixtures of the different treatments, since increasing this factor, decreased the starch content in the mixtures, which has been reported that favors the EI (Van der Sman & Broeze, 2013). Similarly, the high values of PF by increasing the levels of DNB could be due to the important content of

![Figure 1. Effect of extrusion temperature (°C) and moisture content (%) on the expansion index (EI) (a) and penetration force (PF, N) (b) of TGS expanded by microwave, at DNB = 6.5%.

Figura 1. Efecto de la temperatura de extrusión (°C) y contenido de humedad (%) sobre el índice de expansión (IE) (a) y fuerza de penetración (FP, N) (b) de alimentos BTG expandidos por microondas, a BDN = 6,5%.

![Figure 2](image-url)

![Figure 3](image-url)
dietary fiber in this raw material, which could have produced the collapse of air bubbles, decreasing the expansion and increasing the PF. Brennan et al. (2013) reported that both the formulation and ingredients have a very important role in the final quality of the extruded products. These authors mention that the addition of fiber generally increases the hardness of the extrudates because the expansion of the air bubbles is affected.

**Total color difference (ΔE)**

The ΔE indicates changes in color between unprocessed and processed samples, and can provide information about the degree of browning reactions such as Maillard reactions, degree of cooking, caramelization and pigment degradation, which could be carried out during the extrusion process (Altan, McCarthy, & Maskan, 2008). The effect of MC and DNB on the values of ΔE at a constant level of ET = 115°C is presented in Figure 4(a). It can be observed that the highest values of ΔE (>27) were presented at low MC (<24%) and high DNB (>9%). The high values of ΔE obtained in the treatments with low levels of MC could be due to an increased residence time of the samples because of a high friction presented inside the extruder under these conditions. Maillard or caramelization reactions could have produced a greater darkening of extruded samples in comparison with the unprocessed samples, increasing thus the ΔE values. Camire, Violette, Dougherty, and McLaughlin (1997) reported that the residence time of samples inside the extruder may affect the ΔE values in the products, indicating that shorter residence times produce minor ΔE changes and less damage to the food pigments, affecting in less extent the color of the products. This behavior agrees with that reported by Delgado-Nieblas et al. (2012), who...
produced TGS expanded by microwave heating, obtaining the highest values of ΔE at low levels of MC combined with high contents of winter squash flour. Additionally, some compounds present in DNB such as gums and pectins could have presented a lubricating effect (Pai, Blake, Hamaker, & Campanella, 2009), increasing the fluidity of the mixtures in the extruder, promoting less residence time and heat degradation of carotenoids.

**Sensory acceptability (SA)**

In TGS products, generally texture, appearance and flavor are the main sensory attributes being evaluated. Figure 5 shows the effect of ET and MC on the SA of the TGS at constant level of DNB = 6.5%. The highest values of SA (57–64, “I like moderately”, LAM scale) were presented at intermediate levels of ET (~115°C) and MC (~27%). This favorable acceptability by the panelists could be due to the crunchy properties that exhibited the analyzed snack foods. At this point, the values of EI >5 and PF <5 N presented by the TGS were close to the values exhibited in commercial products (4.8 and 2.4 ± 0.80 N, respectively). The EI and PF are important quality characteristics of the TGS, which have high influence on their acceptability by consumers (O’Shea, Arendt, & Gallagher, 2014). In the present study, the SA showed a moderate inverse correlation with the factor DNB ($r = -0.64$, $p = 0.004$). DNB levels above 7% caused that SA values decreased dramatically throughout the whole range of MC (Figure 6), in which the panelists stated that the snacks presented a bitter taste, probably due to the higher presence of flavonoid compounds (Moriguchi, Kita, Hasegawa, & Omura, 2003), causing a decrease in the SA values. These results are similar to that reported by Fu, Shiau, and Chang (2014), who reported that the addition of levels higher than 6% of *Citrus mitis* B. in bread production caused a decrease in the SA of this product. In the present work, the panelists commented that those TGS presenting EI >6, PF <4 and DNB ~ 6.5% had good texture, appearance and flavor.

**Total carotenoids (TC)**

The effect of MC and DNB on the TC content for TGS at a constant level of ET = 115°C can be observed in Figure 4b. It can be observed that the highest values of TC (>120 µg/g db) were found at high DNB (>9.5%) throughout the MC range. The TC content presented a high positive correlation with the factor DNB ($r = 0.76$, $p < 0.001$). This behavior could be due to the important content of TC provided by DNB (2.3 ± 0.49 mg/g db), which was higher than that found in other raw materials used in the present study, such as whole yellow corn flour (0.168 ± 0.004 mg/g db). Additionally, the increase in the ΔE values at high levels of DNB are mainly due to an increase in the b* parameter value (data not shown) of the samples, which presented a significant positive correlation ($r = 0.93$, $p < 0.001$) with the ΔE. High values of b* parameter are related with the yellow-orange coloration present in DNB.

![Figure 4](image4.png)

**Figure 4.** Effect of moisture content (%) and dehydrated naranjita bagasse content (%) on the total color difference (a) and total carotenoids content (µg/g db) (b) of TGS expanded by microwave, at ET = 115°C.

![Figure 5](image5.png)

**Figure 5.** Effect of extrusion temperature (°C) and moisture content (%) on the sensory acceptability of TGS expanded by microwave, at DNB = 6.5%.

**Figure 5.** Efecto de la temperatura de extrusión (°C) y contenido de humedad (%) sobre la aceptabilidad sensorial de alimentos BTG expandidos por microondas, a BDN = 6.5%.

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Conclusions

The mathematical models used for the analysis of different response variables showed values of $R^2_{\text{adj}} > 0.67$, $p$ of F (model) $\leq 0.001$, showing no lack of fit (except for EI and TC). The factor that showed the major effect on the response variables EI and PF was ET, whereas the greatest effect on $\Delta E$, TC and SA was presented by DNB. The optimum conditions of the extrusion process obtained with the numerical method were ET = 125°C, MC = 23% and DNB = 8.03%. The real values obtained in the validation of the optimum processing conditions were similar to the values predicted by the model in different responses. The snacks obtained at optimal conditions showed textural and expansion properties similar to or better than commercial snacks. Also, these products showed important SA and TC content. The results of the present study indicate that it is possible to obtain TGS extrusion products with acceptable physical and sensory properties, in addition to important TC levels. The consumption of these fat-free snacks could have benefits in the human health, due to the use of raw materials rich in carotenoids that are regarded as natural antioxidants.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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