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Propiedades fisicoquímicas de bocadillos extrudidos listos-para-comer de mezclas de plátano verde, subproductos de piña y stevia
Physicochemical properties of extruded ready-to-eat snack from unripe plantain blends, pineapple by-products and stevia

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Resumen

El objetivo de esta investigación fue evaluar el efecto de la temperatura de extrusión (TE 120 - 180 °C), contenido de humedad de alimentación (CHA 16 - 25 g/100 g), proporción de subproductos de piña (PSP 0 - 30 g/100 g) en la harina de plátano verde y el contenido de stevia (CST 0 - 5 g/100 g) sobre las propiedades fisicoquímicas y aceptación sensorial de los bocadillos extrudidos listos para comer, atreves de un diseño de experimentos central compuesto, utilizando una extrusor de un solo tornillo con una relación de tornillo de compresión de 3:1. Los resultados se analizaron por superficie de respuesta. El aumento en CHA, PSP y CST disminuyó ($p < 0.05$) el índice de expansión (IE). El aumento en TE disminuyó ($p < 0.05$) la densidad aparente (DA), el índice de absorción de agua (IAA), el índice de solubilidad en agua (ISA) y la diferencia total de color (ΔE). El aumento en CHA disminuyó IE, IAA, y aumentó DA, ISA ($p < 0.05$). El aumento en PSP disminuyó IE, ISA, y aumentó DA, dureza (D) y ΔE ($p < 0.05$). El aumento en CSC disminuyó ($p < 0.05$) IE y aumentó DA y D. Los tratamientos con mayor aceptabilidad general fueron aquellos que contenían 15 y 30 g/100 g de PSP y CST = 2.5 g/100 g, los cuales fueron obtenidos a TE 150 ºC y 20.5 g/100 g de CHA, sin afectar las propiedades fisicoquímicas.

Abstract

The aim of this research was to evaluate the effect of extrusion temperature (ET 120 – 180 °C), feed moisture content (FMC 16 - 25 g/100 g), pineapple by-products proportion (PBP) (0 - 30 g/100 g) in the unripe plantain flour, and the stevia content (STC 0 - 5 g/100 g) on the physicochemical properties and sensory acceptance of ready-to-eat extruded snacks, through a central compound design, using a single-screw extruder with a compression screw ratio of 3:1. The results were analyzed by response surface. The increase in FMC, PBP and STC decreased ($p < 0.05$) the expansion index (EI). The increase in ET decreased ($p < 0.05$) the apparent density (AD), water absorption index (WAI), water solubility index (WSI) and total color difference (ΔE). The increase in FMC decreases EI, WAI, and increase AD and WSI ($p < 0.05$). The Increase in PBP decreased EI, WSI, and increase AD, hardness (H) and ΔE ($p < 0.05$). The increase in STC decreased ($p < 0.05$) EI, and increase AD and H. The treatments with greater general acceptability were those that contained 15 and 30 g/100 g of PBP and STC 2.5 g/100 g, and they were obtained at ET 150ºC and 20.5 g/100 g of FMC, without affecting the physicochemical properties.

Introduction

Current trends in the use of agro-food industry by-products or waste are increasing worldwide, increasing their added value, and providing economic, environmental and health benefits (González *et al*., 2019). From which compounds rich in fibers, proteins or bioactive compounds can be obtained, being promising sources of a large amount of nutrients for the development of new products and giving an added value to these agro-food industry waste (Korkerd *et al*., 2016).

In this sense, in the pineapple industry, 76 % are waste (skin and core), of which 99.2 % is insoluble fiber and 0.8% is soluble fiber (Martínez *et al*., 2012; Rivera-Mirón *et al*., 2020).

According to the FAO in 2018, 27,924,287 tons of pineapple were produced worldwide (FAO, 2020), producing 21,222,458.12 tons of waste (76 %), presenting an opportunity niche for the generation of a new product rich in fiber, and with a high consumption.

The consumption of ready-to-eat foods has increased notably in the last decade (Dos Santos Fernández *et al*., 2002), becoming an important part of the diet for the world population (Thakur and Saxena, 2000), being relatively cheap and ready for consumption for all age groups (Caltinoglu *et al*., 2014), therefore are consumed in the form of breakfast cereals and snacks. However, there is interest in incorporating new raw materials to improve their nutritional properties (González *et al*., 2000). Some research has been carried out in this regard, for example raw materials rich in proteins such as pumpkin seeds, defatted soy flour, whey, among others (Navarro-Cortez *et al*., 2016, Mridula *et al*., 2017; Onwulata *et al*., 2010), as well as with fiber: pineapple pomace, maize grits, carrot pomace, carambola pulp, among others (Borah *et al*., 2016; Carvalho and Mitchell, 2000; Selani *et al*., 2014; Kaisangsri *et al*., 2016; Rivera-Mirón *et al*., 2020), however always based on cereals and starch of these (corn, wheat, among others). One of the most important processes in the development of snacks is extrusion (Cuj-Laines *et al*., 2018). Due to its technological advantages over traditional food processing techniques (Caltinoglu *et al*., 2014), which highlights the time saving, versatility in the creation of new products, the variety of textures, flavors, size and its efficiency, both productive as energy (González *et al*., 2002). The most important variables are the process temperature, the moisture content in the feed, the speed of the screw, the compression force of the screw, and chemical composition of the raw materials. In this sense, the pineapple by-product can be mixed with another raw material to make a fiber-rich product through the extrusion process. The unripe male plantain flour is rich in carbohydrates, that is, 75 % of which 42 – 47 % is resistant starch and contains 61.3 to 85.4 g/100 g of starch (db) (Kaur *et al*., 2015; Wang *et al*., 2017; García-Valle *et al*., 2019), also the fruit is rich in iron, potassium and vitamin A (Ilelaboye, 2019). The use of sweeteners in extruded products such as sugar has been extensively investigated (Pitts *et al*., 2014). Stevia (*Stevia rebaudiana*) is a plant native to Brazil and Paraguay in South America (Anton *et al*., 2010), has various sweetening compounds, of which stand out: stevioside (5 – 10 %), rebaudioside A (2 – 4 %), rebaudioside C (1 – 2 %) and dulcoside A (0.5 – 1 %) (Midmore and Rank, 2005), which register 20 to 30 times as sweet as sugar cane and steviosides up 200 to 300 times sweeter than the refined sugar of the cane, ideal for the consumption of all kinds of people for not contributing calories.

Therefore, the aim of this research was to evaluate the effect of temperature extrusion, feed moisture content and the proportion of pineapple by-products (*Ananas comosus*) in unripe male plantain flour (*Musa paradisiaca* AAB) and the content of stevia about some physical, functional properties and sensory acceptance of extruded snacks rich in fiber sweetened with stevia.

Method

Raw Materials

Unripe male plantain (*Musa paradisiaca* AAB) was used in stage 3 of maturity according to the scale of Faisant *et al*. (1995). The plantain was purchased at the local market of the City of San Juan Bautista Tuxtepec, Oaxaca, Mexico. The plantain was cut into 3 mm slices and dried at 60 °C for 3 h, milled and sieved until obtaining a particle size 0.425 mm (Sieve No 40), with the following composition (g/100 g), moisture 11.07, ash 2.14, lipids 0.31, proteins 2.92, total dietary fiber 9.37 and carbohydrates 74.19. The by-products pineapple was donated by the Santa Mónica S.A de C.V Products Plant located in the city of Loma Bonita Oaxaca, Mexico. The by-product consisted of pineapple skin and core, dried at 60 ºC for 8.5 h, milled and sieved until obtaining a particle size 0.425 mm (Sieve No 40), with the following chemical composition (g/100 g) moisture 6.13, ashes 2.71, lipids 1.09, proteins 9.15, total dietary fiber 36.16 and carbohydrates 34.75. Stevia (steviol glycosides (2.5 g/100 g), isomalt (1 g/100 g) and commercial sugralosa (0.6 g/100 g) of the Svetia® brand (Metco S.A de C.V. Mexico) was used.

Extrusion process

The extrusion was performed in a single screw laboratory extruder (Brabender, Model E19/25 D, Instruments Inc. Germany) with a diameter of 19 mm, a length:diameter ratio of 20:1, a compression ratio of the screw 3: 1 and a cylindrical 3 mm die. The flours were mixed by hand until the mixture was homogeneous and the moisture content adjusted according to the design of experiments (table 1). The temperature profile was kept constant at 50 °C zone 1, 80 °C zone 2, 100 °C zone 3 and zone 4 from 120 to 180 °C, according to the design of experiments (table 1).

Table 1. Composite central design used and experimental response values.

Run	Extrusion process variables				Responses					
	ET (°C)	FMC (g/100 g)	PBP (g/100 g)	STC (g/100 g)	EI	AD (g cm^{-3})	H (N)	WAI (g/100 g)	WSI (%)	ΔE
1	135	18.25	7.50	1.25	4.95	1.80	108.77	16.33	64.88	50.04
2	165	18.25	7.50	1.25	5.86	1.24	71.70	15.70	76.93	52.05
3	135	22.75	7.50	1.25	4.98	1.71	100.08	18.41	100.36	47.77
4	165	22.75	7.50	1.25	4.43	1.91	135.84	16.18	73.45	50.46
5	135	18.25	22.50	1.25	4.37	1.76	116.96	15.10	70.05	49.70
6	165	18.25	22.50	1.25	4.11	2.31	114.27	14.88	49.19	49.52
7	135	22.75	22.50	1.25	4.61	1.62	153.48	18.42	108.13	47.66
8	165	22.75	22.50	1.25	3.82	2.05	134.42	17.00	76.06	50.17
9	135	18.25	7.50	3.75	3.54	2.58	118.63	14.93	53.69	48.66
10	165	18.25	7.50	3.75	5.32	1.33	104.64	16.74	100.37	47.40
11	135	22.75	7.50	3.75	3.15	2.14	113.73	14.29	39.08	46.92
12	165	22.75	7.50	3.75	5.67	1.20	122.76	18.66	95.51	41.95
13	135	18.25	22.50	3.75	4.31	1.74	138.54	16.82	52.32	49.86
14	165	18.25	22.50	3.75	4.58	1.38	100.00	17.51	88.78	50.02
15	135	22.75	22.50	3.75	4.24	1.65	141.38	15.19	65.87	48.60
16	165	22.75	22.50	3.75	3.95	1.69	133.67	17.66	62.89	48.01
17	120	20.50	15.00	2.50	4.10	1.71	146.75	18.17	28.45	48.16
18	180	20.50	15.00	2.50	4.30	1.66	97.97	19.78	30.35	49.44
19	150	16.00	15.00	2.50	4.18	1.67	124.78	18.61	28.44	48.84
20	150	25.00	15.00	2.50	3.91	1.55	120.79	16.37	22.25	48.77
21	150	20.50	0.00	2.50	3.78	1.77	123.84	17.76	22.23	47.28
22	150	20.50	30.00	2.50	5.68	0.49	97.52	14.67	17.74	38.81
23	150	20.50	15.00	0.00	4.65	0.87	109.30	17.54	19.50	39.88
24	150	20.50	15.00	5.00	5.15	0.75	126.23	15.29	17.55	39.95
25	150	20.50	15.00	2.50	4.18	1.11	147.43	15.39	18.41	42.27
26	150	20.50	15.00	2.50	5.02	0.58	96.75	15.89	16.57	39.89
27	150	20.50	15.00	2.50	4.79	1.04	105.45	17.22	17.78	39.84
28	150	20.50	15.00	2.50	4.66	0.96	125.44	17.76	16.28	39.89
29	150	20.50	15.00	2.50	4.68	0.78	143.58	17.24	20.63	42.30
30	150	20.50	15.00	2.50	3.84	0.98	102.53	14.29	18.74	39.50

ET: Extrusion Temperature; FMC: Feed Moisture Content; PBP: Pineapple By-products Proportion; STC: Stevia Content; EI: Expansion Index; AD: Apparent Density; H: Hardness; WSI: Water Solubility Index; WAI: Water Absorption Index; ΔE: Total color difference.

Characterization of the products obtained

Expansion index (EI) and apparent density (AD)

The EI was calculated by dividing the average diameter of the extruded product between the inside diameter of the extrusion die. Measurements were made with the help of a digital vernier (Science Purchase, 0604CAL6, USA), fifteen measurements were made per treatment (Rodriguez-Miranda *et al*., 2011). The AD was analyzed according to the methodology reported by Wang *et al.* (1993). Fifteen extrudate samples of each treatment of approximately 5 cm selected at random, the diameter (D), length (L) and weight (M) were measured. The AD was calculated using the following equation (Eq 1) and the results were expressed in g cm^{-3}.

$$\mathrm{AD} = \frac{4\ x\ M}{\pi\ x\ D^2 x\ L} \qquad \text{Eq. 1.}$$

Hardness (H)

The H of the samples was measured in a Texture Analyzer (TA-XT2i Plus Texture Analyzer, Texture Technologies Corp., Scarsdale UK). Hardness in N was determined by measuring the maximum force required to break the extruded samples (50 mm long) with twenty determinations were made per treatment.

Water absorption index (WAI) and Water solubility index (WSI)

The WAI and WSI of extrudates was determined according to the method of Anderson *et al.* (1969). Extruded milled material (1 g) was suspended in distilled water (10 mL) at 25 °C, the samples were centrifuged for 15 min at 1000 *x* g. The supernatant was decanted in a constant weight capsule. The WAI was calculated as the weight of the sediment obtained after the elimination of the supernatant as weight per unit of original solids as dry base (g/g). The supernatant that was obtained in the determination of WAI, which was dried in a convection oven at 100 °C for 24 h. The WSI is the weight of dry solids in the dry supernatant expressed as a percentage (%) of the original weight of the sample on a dry basis.

Total color difference (ΔE)

The color measurements were used in a colorimeter (Ultra Scan Vis Hunter Lab Associates Laboratory, Inc., Reston, VA, USA), opting for the values of *L**, *a** and *b**. The instrument was calibrated against a standard white tile ($L*_s$ = 100.31, $a*_s$ = -0.40, $b*_s$ = 0.01). The samples were compared with that standard to obtain the total color difference (ΔE) (Eq 2). The sample was read four times per treatment.

$$\Delta E = [(L^*{}_s - L^*)^2 + (a^*{}_s - a^*)^2 + (b^*{}_s + b^*)^2]^{1/2} \qquad \text{Eq. 2.}$$

Sensory evaluation

A hedonic test was carried out on the six extruded products with the highest expansion index (Cuj-Laines *et al*., 2018). Each untrained panelist was served the extruded samples of approximately 50 mm in length in plastic plates (3 pieces) labeled with a 3-digit code and a glass with water to neutralize any flavors that may remain from the previously evaluated sample. The panelists evaluated the attributes of appearance, color, aroma, texture, taste, and general acceptance; using a hedonic scale of seven points (1 = I dislike extremely, 7 = I like it extremely) to 100 panelists (Simons *et al*., 2015). The attribute of aroma they were asked to evaluate according to the degree to which they liked the smell of the samples.

Experimental design and data analysis

A design of central composite experiments was carried out (table 1) with four independent variables: extrusion temperature (ET 120 – 180 °C), feed moisture content (FMC 16 - 25 g/100 g), pineapple by-products proportion (PBP 0 - 30 g/100 g) in the unripe plantain flour and the stevia content (STC 0 - 5 g/100 g). The response variables were: expansion index (EI), apparent density (AD), hardness (H), water absorption index (WAI), water solubility index (WSI), and total color difference (ΔE). The results were analyzed by multiple linear regression with the commercial statistical package (Statistica 8, StatSoft inc., Oklahoma, USA.). The experimental data were fitted to a quadratic model and the regression coefficients and the statistical significance of the terms of the regression were examined by means of an analysis of variance (ANOVA), for each response.

Results and discussion

Effect of extrusion temperature (ET), feed moisture content (FMC), pineapple by-products proportion (PBP) and stevia content (STC) on extrudates

Regression coefficients

Table 2 shows the regression coefficients for all the responses analysed. Second order polynomial models showing the relationships between ET, FMC, PBP, and STC and the response variables EI, AD, H, WAI, WSI, and ΔE were obtained by regression. The regression models were significant ($p < 0.05$) for all the responses, except for the WAI, with a coefficient of determination (R^2) in the range of 0.63-0.90. The models for EI, WSI, and ΔE did not show a Lack of Fit ($p > 0.05$). ET presented a significant effect ($p < 0.05$) in its linear term on AD, WSI and ΔE, and quadratic on AD, WAI, and ΔE. The FMC presented significant effect ($p < 0.05$) in its linear term on EI and AD, and in its quadratic term on WAI, and WSI. The PBP presented a significant ($p < 0.05$) linear effect on EI, AD, H, WSI, and ΔE, and in its quadratic term on EI, AD, WSI, and ΔE. The STC presents a significant ($p < 0.05$) linear effect on EI, AD, and H, and in its quadratic term on AD, and WSI. The ET-FMC, ET-PBP and ET-STC interactions presented significant effect ($p < 0.05$) on AD, while the FMC-PBP interaction on WAI and WSI. The FMC-STC interaction significant effect ($p < 0.05$) on AD.

Table 2. Coefficients estimated by multiple linear regression of the physicochemical characterization of extruded snacks.

Coefficients	EI	AD	H	WAI	WSI	ΔE
Intercept	**4.07**	**1.62**	**124.63**	**18.06**	**32.43**	**48.41**
Linear						
ET	0.04	**-0.43**	-1.43	-0.15	**-23.15**	**-7.85**
FMC	**-0.30**	**0.12**	5.71	0.08	-2.41	-0.30
PBP	**-0.32**	**0.13**	**10.82**	-0.31	**-6.10**	**1.98**
STC	**-0.20**	**0.11**	**8.16**	0.02	-3.40	-0.48
Quadratic						
ET^2	0.11	**-0.09**	-4.68	**-0.67**	-0.77	**-2.44**
FMC^2	0.07	0.00	-3.80	**-0.62**	**6.21**	-1.24
PBP^2	**0.26**	**-0.07**	1.56	-0.06	**7.26**	**-1.88**
STC^2	0.12	**-0.05**	-0.92	-0.41	**8.11**	-0.17
Interactions						
ET-FMC	-0.09	**0.05**	3.44	0.04	-3.03	1.77
ET-PBP	0.12	**-0.05**	5.84	0.28	3.91	0.50
ET-STC	0.19	**-0.12**	-4.83	0.34	1.99	0.62
FMC-PBP	0.02	-0.00	-6.97	**-0.88**	**-6.62**	0.95
FMC-STC	0.18	**-0.06**	-1.15	-0.15	1.22	0.08
PBP-STC	0.07	-0.02	-7.74	0.30	0.63	0.03
P-value for model	0.002	0.132	0.042	0.684	0.001	0.005
R^2	0.78	0.63	0.68	0.67	0.70	0.900
Lack of Fit	0.110	0.003	0.006	0.028	0.160	<0.001

The values in bold are the significant terms of the regression model ($p < 0.05$). Regression coefficients obtained are in terms coded. ET = Extrusion Temperature (°C); FMC = Feed Moisture Content (g/100 g); PBP = Pineapple By-products Proportion (g/100 g); STC = Stevia Content (g/100 g); EI = Expansion Index; AD = Apparent Density; H = Hardness; WSI = Water Solubility Index; WAI = Water Absorption Index; ΔE = Total color difference.

Expansion index (EI), apparent density (AD), and hardness (H)

The EI values of the extruded products vary from 3.15 - 5.86 (table 1). In fig. 1a it can be seen that EI decreased linearly with FMC, negative sign of the linear effect (table 2) indicated that the responses tended to reach stationary points (maximum) at low FMC values, and decreased quadratically with PBP. The positive sign of the quadratic effect of PBP (table 2) indicated that the responses tended to reach stationary points (minimum) at high values of PBP (fig. 1b). This is because the increase in FMC leads to a lower input of specific mechanical energy, which leads to the reduced physicochemical transformation of the starch and this leads to a reduced expansion (Kaisangsri *et al*., 2016). The ET favors the expansion of the snacks, this is due to high ET, and low moisture content, causing structural transformations of biopolymers, transitions and phase transformations that lead to the formation of air bubbles within the starch and preserving them after of the exit of the extruder material (Moraru and Kokini 2003).

The increase in the expansion index with the operating temperature was attributed to its higher degree of gelatinization. In addition, the operation of high-temperature extrusion causes overheating of the moisture in the sample. When the dough left the die outlet, the sudden pressure drops caused the moisture to evaporate rapidly, leading to bubble formation and product expansion (Kantrong *et al*., 2018). This is because operating an extruder at a higher temperature will increase the degree of overheating of the water inside the extruder barrel, which helps to increase bubble formation and also decrease the viscosity of the melt (Kantrong *et al*., 2018).

In fig. 1b, it is observed that the increase of the STC does not increase the IE, but the increase in PBP the IE decreases, since the fiber content has a direct effect on the extruded expansion, this is due to the fact that the expansion is dependent of the amount of fiber added negatively.

However, this depends on the type of fiber source used, Masli *et al.* (2018), mention that the inclusion of apple pomace showed potential to produce extrudates with a significantly greater expansion than the control of corn starch.

The increase of the fiber level in the mixture could have caused a maldistribution in the starch matrix during the extrusion, which could have resulted in the aggregation of the fiber in random points of the starch matrix, in addition to the effect of dilution of the starch because of the addition of PBP in BF which hindered the formation of bubbles (cells) during the expansion process due to the high levels of pineapple fiber. The presence of fiber broke the cell walls and prevented the gas bubbles from expanding to their maximum potential, in addition to reducing the viscosity of the melt in the extruder (Ganjyal *et al*., 2004; Kaisangsri *et al*., 2016; Borah *et al*., 2016; Mridula *et al*., 2017). These results are in accordance with that reported by Alam *et al.* (2016), Sozer and Poutanen, (2013) and Selani *et al.* (2014): mention that above 10 to 15 % of fiber in the formulation begins to interfere with the continuous structure of the melt and prevent its elastic deformation and reduce the capacity of gas retention during the expansion.

The increase in STC showed a negative effect on the expansion, an effect reported by other authors (Carvalho and Mitchell, 2000, Pitts *et al*., 2014). This is because the sugar content causes a reduction in the growth of the bubbles during the process and an increase in the degree of contraction when leaving the extruder exit die (Pitts *et al*., 2014).

The AD and its relationship with the EI are important parameters of the expanded products, a negative correlation has been observed between the expansion ratio and the density of the extrudates (Rodríguez-Miranda *et al*., 2014; Charunch *et al*., 2011), therefore, the greater expansion a low apparent density and vice versa. The AD values have a range of 0.49 - 2.58 (g cm^{-3}) (table 1). Analyzing figs. 1c and 1d, it can be seen that AD increased quadratically with ET, PBP and STC. The negative sign of the quadratic effect ET, PBP and STC (table 2) indicated that the response tended to reach stationary points (maximum) at high ET, PBP and STC values. Fig. 1d shows that increasing the PBP and STC the AD increases in the extrudates. At high FMC and low ET an increase in AD is obtained, as a result of the expansion achieved in extruded products. The reduction of AD could be the result of partially liquefied starch that adheres to the cellulose walls and reduces expansion, which increases the density of the product (Gumul *et al*., 2015). Ainsworth *et al.* (2007) observed an increase in AD with the increase in fiber levels from 10 to 30 % in the formulation. The increase in AD with the increase in STC is due to the fact that it prevents bubbles from forming and causes an increase in the degree of contraction of the extrudate when leaving the extruder (Pitts *et al*., 2014). The ET-FMC interaction has a negative effect because the increase in ET (120 - 180 ºC) and the increase in FMC (16 - 25 g/100 g) combined decreases the EI therefore the maximum temperature (180 ºC) and the maximum FMC (25 g/100 g) does not reach to form the bubbles of air to the interior of the product by the excess of humidity and increases the density of the final product. Borah *et al.* (2016) mention that the increase in the moisture content of the feed can increase the bulk density, while the increase in the speed of the screw and the temperature of the barrel can reduce the apparent density. While the ET-PBP interaction decreases the AD, the increase in PBP inhibits the expansion of the product at the exit of the die, due to the dilution of the starch present in the BF, however, the increase of the ET helped the maximum expansion of the final product and with this decrease the AD. The ET-STC and FMC-STC interactions decreased the AD, the increase in temperature and the content of stevia in the mixture helped the expansion and therefore the AD decreased, as well as the increase in moisture content.

The H of extruded materials is associated with the expansion, bulk density and cellular structure of the product. The values of the H present a range of 71.7 to 153.48 (N) (table 2). The increase in PBP and STC presents a significant effect ($p < 0.05$) positive linear. Analysis of figs. 1e shows that H increased quadratically with FMC and ET. The negative sign of the quadratic effect ET and FMC (table 2) indicated that responses tended to reach (maximum) stationary points at high ET and FMC values. The positive sign of the linear effect STC and PBP (table 2) indicated that the responses tended to reach stationary points (maximum) at high STC and PBP values. Fig. 1f shows that increasing the PBP and STC requires greater force for rupture. The increase in PBP contributed fiber to the mixture, diluted the concentration of starch contained in male plantain flour and the interaction between these components (fiber) and starch, resulting in less expanded, denser products that required greater strength to break to the extruded.

Because of fiber can break the cell wall and prevent air bubbles from expanding to their maximum capacity (Korkerd *et al*., 2016; Ruiz-Armenta *et al*., 2018). Korkerd *et al.* (2016) suggest adding between 10 – 30 % as maximum fiber limits in extruded products in substitution of defatted soybean meal due to the increase in the hardness of the product. While Brennan *et al*. (2013) reported that the addition of fiber generally increases the hardness of the extrudates because the expansion of the air bubbles is affected. Pitts *et al.* (2014) mention that the expansion increase resulted in a product with lower density that was crispier. This is because stevia prevents the expansion of extrudates. Pitts *et al.* (2014) observed a similar tendency to increase the content of salt and sugar, which corresponded to an increase in apparent density and a decrease in the pore size of extruded products.

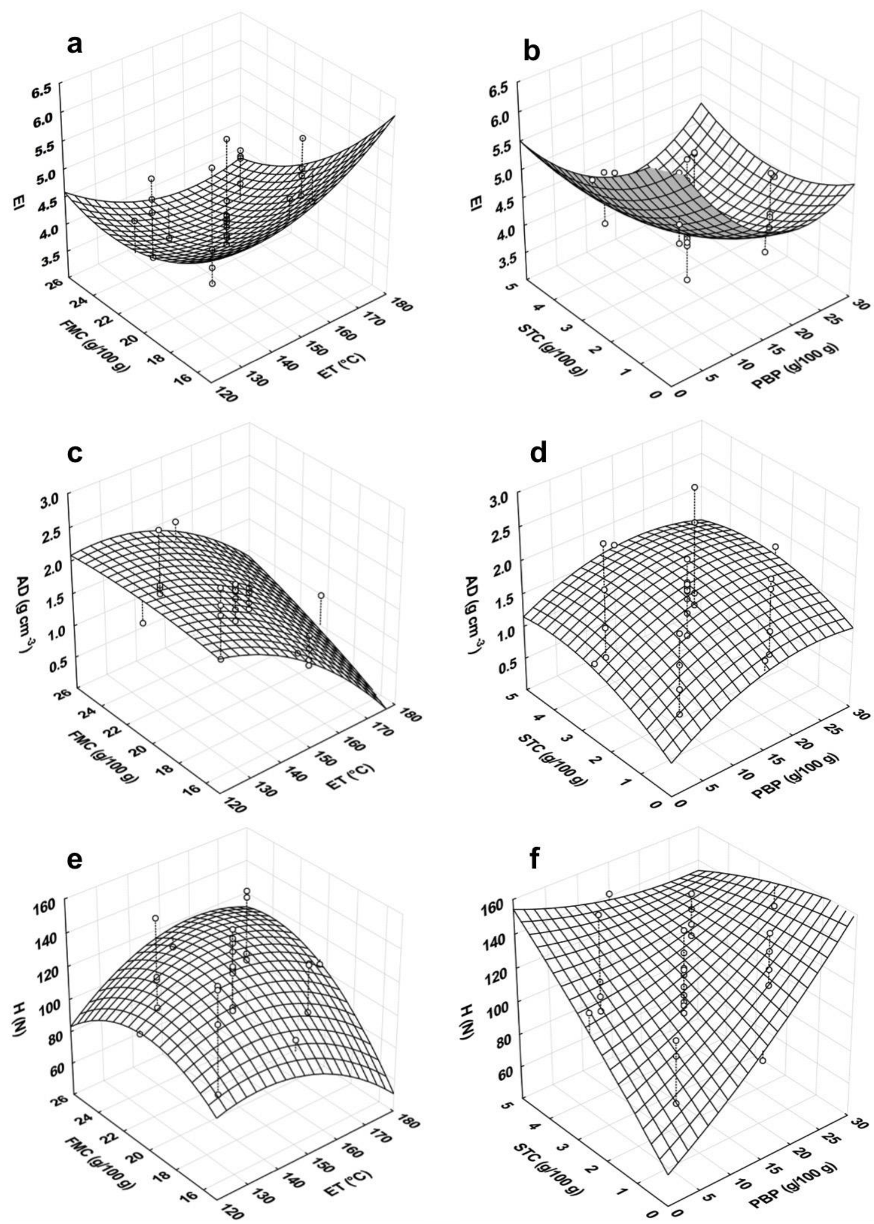

Fig. 1. Response surface plots for **a**) expansion index (EI) as a function of feed moisture content (FMC) and extrusion temperature (ET), **b**) EI as a function of stevia content (STC) and pineapple by-products proportion (PBP), **c**) apparent density (AD) as a function of FMC and ET, **d**) AD as a function of SCT and PBP, **e**) hardness (H) as a function of FMC and ET, **f**) H as a function of SCT and PBP.

Water absorption index (WAI) and Water solubility index (WSI)

The WAI values presented a range of 14.29 to 19.78 (g/g) (table 1). The increase of ET and FMC presents a significant effect ($p < 0.05$) negative in its quadratic expressions, and in the interaction of FMC-PBP. The analysis of figs. 2a shows that WAI increased quadratically with FMC and ET. The negative sign of the quadratic effect ET and FMC (table 2) indicated that the responses tended to reach stationary points (maximum) at intermediate values of ET and FMC. Fig. 2b shows that WAI increased linearly with increasing STC and PBP. The positive sign of the linear effect STC and PBP (table 2) indicated that responses tended to reach stationary points (maximum) at high STC and PBP values. In fig. 2a it can be seen that the largest WAI were those that were processed at an ET 140 at 165 °C and an FMC 20 at 22.75 g/100 g, on the other hand, in fig. 2b it can be seen that the PBP and STC have no significant effect ($p < 0.05$) on the WAI. This is because the WAI depends on the availability of hydrophilic groups and the gel-forming capacity of macromolecules (starch, proteins and fiber) and are influenced by factors such as temperature and moisture content (Selani *et al*., 2014; Kaur *et al*., 2015). As well as the starch granules after reaching a maximum degree of swelling, they undergo structural damage, decreasing the WAI at low FMC and increasing the ET. This is probably due to the dextrinization or fusion of starch that prevails over the gelatinization phenomenon (Sarawong *et al*., 2014). The increased interaction of FMC-PBP decreased WAI, probably to the plasticization of the melt at a higher moisture content. Kaisangsri *et al*. (2016) mention that at high feed moisture (22.5 and 30 g/100 g), the level of carrot pulp had no significant effect on WAI and Altan *et al*. (2008) also reported a decrease in WAI due to competition for water absorption between pineapple pulp and available starch.

The WSI values have a range of 16.28 - 108.13 % (table 1). Analysis of figs. 2c and 2d shows that WSI increased quadratically with FMC, ET, STC, and PBP. The positive sign of the quadratic effect FMC, ET, STC, and PBP (table 2) indicated that responses tended to reach stationary points (maximum) at high MC, ET, STC, and PBP values. The increase of ET and PBP presents a significant negative effect ($p < 0.05$) and linear effects ($p < 0.05$) positive quadratic FMC, PBP, and STC, as well as a negative interaction of FMC-PBP ($p < 0.05$). In fig. 2c it can be seen that the WSI increases at lower ET while the increase in FMC increases this response, on the other hand, in fig. 2d it can be seen that without stevia and higher content the maximum WSI values are obtained, similar with the PBP. The decrease in WSI with the increase in fiber content has also been reported by other authors (Kumar *et al*., 2010; Alam *et al*., 2016; Sarawong *et al*., 2014). Hashimoto and Grossmann (2003) stated that increasing the fiber content decreased the WSI at high temperatures. This is because the WSI of proteins is reduced in extrusion due to denaturation, structural changes and the formation of complexes with other macromolecules such as starch (Fernández-Gutiérrez *et al*., 2004). The increase in FMC decreased WSI because a greater amount of moisture during the extrusion process reduced the degree of gelatinization of the starch and probably acts as a plasticizer caused by the reduction of starch degradation, also due to the lower shear, which the WSI decreases (Hagenimana *et al*., 2006). The interaction of the FMC-PBP decreased the WSI, this is because the increase in PBP increases the fiber content in the mixture and decreases the starch content, and the increase in the FMC, leads to a lower dextrinization of the polymers of starch and, therefore, a decline in WSI. Kaisangsri *et al*. (2016) mention that the increase of the humidity of the food and carrot pulp, leads to a lower dextrinization of the starch polymers and, therefore, to a reduced WSI. Insoluble fiber has a tendency to bind with starch polymers and reduce dextrinization of starch and, therefore, reduces WSI (Kumar *et al*., 2010).

Total color difference (ΔE)

The values of the ΔE present a range of 38.81 to 52.05 (table 1). Analysis of figs. 2e and 2f show that ΔE increased linearly and quadratically with FMC, ET, STC, and PBP. The positive sign of the linear and quadratic effect FMC, ET, STC, and PBP (table 2) indicated that responses tended to reach stationary points (maximum) at high FMC, ET, STC and PBP values. The increase of ET presents a significant effect ($p < 0.05$) linear and quadratic negative and PBP presents a significant effect ($p < 0.05$) linear positive and a significant effect ($p < 0.05$) negative quadratic. Fig. 2e shows that as the ET increases from 120 to 160 °C the ΔE decreases. It is known that the reduction of sugars and proteins (amino acids) in food can react at high processing temperatures and promote non-enzymatic browning (Maillard reaction), resulting in darkening of the final product (Navaro-Cortez *et al*., 2016). Therefore, the observed decrease in ΔE can be attributed to the Maillard reaction, as a consequence of extrusion processing. This effect coincides with that reported by other authors (Mjoun and Romertrater, 2011; Norfezah *et al*., 2011). Furthermore, pigment degradation due to extrusion temperatures could have generated Maillard reaction products that promoted changes in color values, as observed in extruded and unprocessed products (Cuj-Laines *et al*., 2018). Fig. 2f shows that increasing the PBP increases the ΔE can be attributed to the redox reactions between sugars and proteins (amino acids) in foods at high temperatures can promote non-enzymatic browning (Maillard reaction), which results in the darkening of the final product (Nayak *et al*., 2011). Therefore, the observed increase in the ΔE values can be attributed to the Maillard reaction as a result of the extrusion process, however, the STCs do not increase the ΔE, this is because stevia has thermal stability and can be exposed at high temperatures over long periods of time, without losing its properties (Lee, 1979).

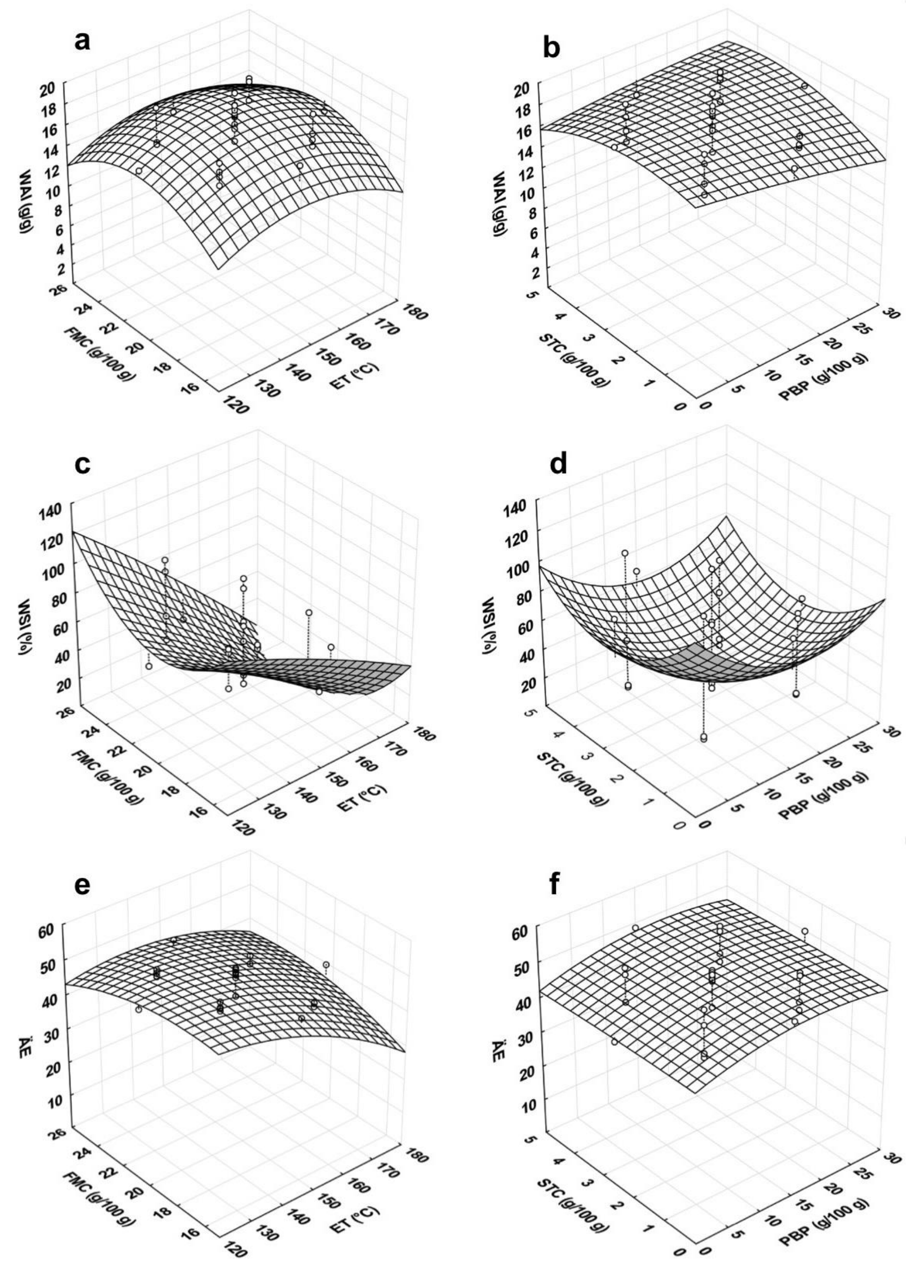

Fig 2. Response surface plots for **a**) water absorption index (WAI) as a function of feed moisture content (FMC) and extrusion temperature (ET), **b**) WAI as a function of stevia content (STC) and pineapple by-products proportion (PBP), **c**) water solubility index (WSI), as a function of FMC and ET, **d**) WSI as a function of SCT and PBP, **e**) Total difference of colour (ΔE) as a function of FMC and ET, **f**) ΔE as a function of SCT and PBP.

Fig 3. Photograph and processing conditions of the selected extruded products.

Sensory analysis

The six extruded products with the highest EI (5.02 to 5.86) selected were the runs: 2, 10, 12, 22, 24 and 26 (table 2, fig. 3). Runs 22 and 26 were the samples with the highest acceptance values (fig. 4). This probably due to the process conditions and STC, both samples were elaborated at ET = 150 °C, FMC = 20.5 g/100 g and STC = 2.5 g/100 g, however, different PBP 30 and 15 g/100 g, respectively. However, run 26 was the one that obtained the highest score in general acceptance (5.41), taste (5.25) and texture (5.30) in the seven-point hedonic scale used. The values correspond to "I like it a little". Other authors have reported that the attributes of color and texture are not only used by the consumer as an indicator of food acceptance, but also as an indicator of the quality of food (Lawless and Heymann, 1998). Roudaut *et al*. (2002) reported that the acceptability of extruded products always depends on the texture of the food (hardness and crunchiness), which stands out as the most important parameter in extruded products. Korkerd *et al*. (2016) suggest adding between 10 – 30 % as maximum fiber limits in extruded products due to the increase in the hardness of the product and the decrease in consumer acceptance.

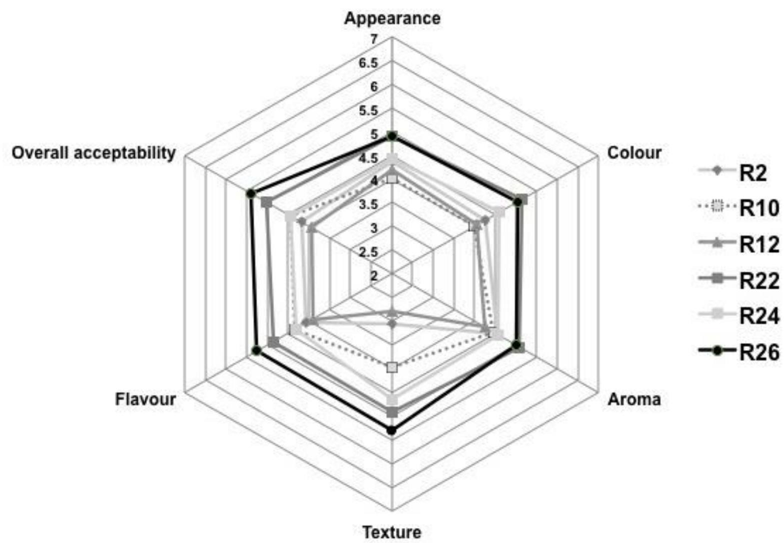

Fig 4. Hedonic scores of selected extruded products.

Conclusion

The incorporation of pineapple by-products in the development of an extruded ready-to-eat snack based on unripe plantain flour affected the expansion and absorption of water of the products obtained. The extrusion temperature affected the apparent density, water absorption, water solubility and total color difference. The increase in feed moisture content (FMC) affected the expansion index and water absorption. While the addition of stevia affected the expansion of the extrudates. The treatments with greater general acceptability were those that contained 15 and 30 g/100 g of PBP and STC = 2.5 g/100 g and obtained at ET = 150 ºC and 20.5 g/100 g of FMC, without affecting the physicochemical properties and acceptance by the consumers. The incorporation of pineapple by-products increases the dietary fiber content of the extruded products, also helped to identify a use for a by-product that is not currently valued and to diversify the use of unripe male plantain and give it an added value, as well as the use of a low-calorie sweetener. Therefore, in this study we developed an extruded ready-to-eat snack with a high fiber content with the use of a pineapple by-product, unripe male plantain flour and sweetened with a low-calorie sweetener (stevia) without affecting its physicochemical properties and its acceptance.

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