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Research article

Impact of extrusion on the physicochemical parameters of two varieties of corn (*Zea mays*)

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Abstract: Ecuador has a significant genetic diversity of maize, which comes in different shapes, sizes and colors and plays a crucial role in food security. This research aimed to evaluate the physicochemical parameters of the extrusion process of two improved maize varieties (INIAP-176 and INIAP-180). The factors under study were two temperatures (140 ℃ and 150 ℃) and two screw speeds (230 rpm and 280 rpm). The applied extrusion conditions showed significant effects on the nutritional content, functional properties, texture attributes and sensory acceptability. The extruded products presented average values of 2.64% moisture, 0.61% ash, 8.54% protein, 0.61% ether extract, 1.55% crude fiber and 88.70 g/100 g were nitrogen-free extract (NFE) about dry weight of sample. Also, extrusion of the two maize varieties at a temperature of 150 ℃ and a screw speed of 280 rpm recorded high values of the expansion index and low levels of bulk density for functional properties. Instrumental texture analysis determined that the best attributes expressed as hardness, fracturability and adhesiveness in the expanded maize obtained from INIAP-176 at a speed of 280 rpm. The application of extrusion in these improved maize varieties allowed the production of high-quality snacks for the consumer.

Keywords: corn grits; extrusion parameters; sensorial attributes; snacks; temperature; texture analysis

1. Introduction

Corn (*Zea mays*) originated in central Mexico approximately 7,000 years ago from a wild grass; Native Americans transformed this species into a food source. Today, corn is grown worldwide and is considered the third most important crop after rice and wheat. The main producers are the United States, China and Brazil [1,2]. The grain contains approximately 72% starch, 10% protein and 4% fat, providing an energy density of 365 Kcal/100 g [3]. Therefore, this crop is considered a fundamental basis for agricultural development and human nutrition [4].

In Ecuador, maize cultivation plays a fundamental role in food security. The per capita consumption of soft maize in Ecuador is around 14.50 kg per year. The grain is grown in the foothills and valleys of the country's Cordillera. These grains come in various types, shapes and colors, constituting the region's genetic wealth [3]. Therefore, the National Maize Program belonging to the INIAP (National Institute of Agricultural Research) develops improved varieties from local germplasm to maintain the characteristics of the popular and in-demand Creole maize varieties [5].

The National Maize Program (National Institute of Agricultural Research) has varieties of hard and soft corn. INIAP-176 and INIAP-180 corns have high grain yield and forage potential. The grains are medium sized, round and yellow, with variations in their intensity. These varieties could be used for both human and animal consumption. However, there are no studies to determine the potential of these varieties in the snacks and extruded products industry [6,7].

Maize presents significant potential in various industries, from which a variety of foods can be developed (snacks, cornflakes, tortillas, among others). It is used as a raw material to produce sweeteners with different degrees of hydrolysis and in animal feed. Additionally, being an important source of starch, it serves as a thickener or stabilizer in instant soups, sauces, juices, pastries, baby food, etc. Moreover, this starch is used in the production of cosmetics and in the pharmaceutical industry as a diluent. The oil present in the embryo is used in cooking and soap preparation, while the stem is used in paper manufacturing [1,8,9].

Since the 1930s, hot extrusion technology has been a thermo-mechanical process that involves the combination of multiple unit operations (mixing, shearing, plasticizing, melting, cooking, fragmentation, among others) and has allowed the food industry to manufacture a wide range of extruded products from different cereals, such as corn, as well as some legumes, roots and tubers [10,11]. It is characterized as a versatile, low-cost and efficient food processing technology [12] since it minimizes nutrient losses in the raw materials used and extends the shelf life of the products obtained, as it involves high temperatures in relatively short times (HTST) [13]. However, changes occur during the process, such as gelatinization, solubilization and dextrinization of starches; the raw materials must contain a minimum starch content of 60–70% to achieve adequate swelling of the molecules, a higher index of expansion and a lower bulk density and obtain a product with uniform and elastic texture [14,15].

Also, due to high temperatures, protein denaturation, enzyme and antinutritional component inactivation occur [14]. In the case of proteins, disulfide bonds are broken and new electrostatic and hydrophobic interactions are formed, resulting in the formation of new structures [13]. Lipids can form a lipid-amylose complex, generating modifications in the physicochemical properties of these products; levels higher than 5% of lipids reduce expansion and influence the degree of starch gelatinization [12,14,16].

Some research has determined that there may be a decrease in the content of insoluble fiber and an increase in soluble fiber, probably due to the inhibition of starch gelatinization [17]. Regarding minerals, the absorption of these compounds could be improved since extrusion deactivates antinutritional factors (tannins and phytates) [14].

Through this study, the aim is to evaluate the effect of the extrusion process on the physicochemical parameters of two improved varieties of corn (INIAP-176 and INIAP-180) from the Santa Catalina-INIAP Experimental Station and determine that these species are suitable for the application of this technology.

2. Materials and methods

2.1. Raw material

For the extrusion process, two varieties of corn (INIAP-176 and INIAP-180) from the National Maize Program of the Santa Catalina-INIAP Experimental Station were used. INIAP-176 was generated in the program and consisted of 49 "Guatemalan" corn lines that were introduced in 1962, while variety INIAP-180 was released between 1985 and 1986, from the crossbreeding of several varieties: INIAP-176, INIAP-178, INIAP 176 x Pool 4B, ICA. V-507 and MB-517 x ICA. V-507, from the International Maize and Wheat Improvement Center (CIMMYT) [18]. These varieties were selected for this study because they showed adequate grain yield and have important agro-industrial use.

2.2. Sample preparation

The selection and cleaning of corn grains were carried out, and then they were subjected to a milling process in a Corona electric mill (Landers y Cia S.A.S, Medellín, Colombia) until they reached a particle size of 2.80 mm in diameter. The corn grits were placed on a series of sieves (Gilson Company Inc, model SS-15, USA) in order to select particles with a diameter of 2.80 mm. The samples were packed and sealed in polypropylene bags and stored at room temperature until use.

2.3. Extrusion process

The extrusion process was carried out in a single-screw extruder (Sermaconi, Quito, Ecuador). Prior to this, the corn grits were moistened to reach 15% of humidity. The samples were placed in the extruder, which was operated at two screw speeds of 230 rpm and 280 rpm, while controlling two process temperatures (140 ℃ and 150 ℃) in the extrusion chamber. The following conditions were kept constant in the equipment. The feed rate to the equipment was kept constant at 2 kg for each sample. The blade speed was set at 1600 rpm, and die pressure was 190 Bar. The nozzle diameter was 2.50 mm. The extruded products were packed and sealed in polypropylene bags and stored at room temperature until analysis. The process flow diagram is shown in Figure 1.

2.4. Analysis methods

2.4.1. Chemical analysis

The moisture content, protein, fiber, ether extract and ash content in the raw material and extrudates were determined according to standardized methods of AOAC. Nitrogen free extract (NFE) was calculated by difference, using the following formula. In the case of protein was calculated with nitrogen conversion factor of 6.25 [19].

$$NFE\left(\frac{g}{100\,g}\,dry\,weight\,of\,the\,sample\right) = 100 - (ash + protein + ether\,extract + crude\,fiber) \quad (1)$$

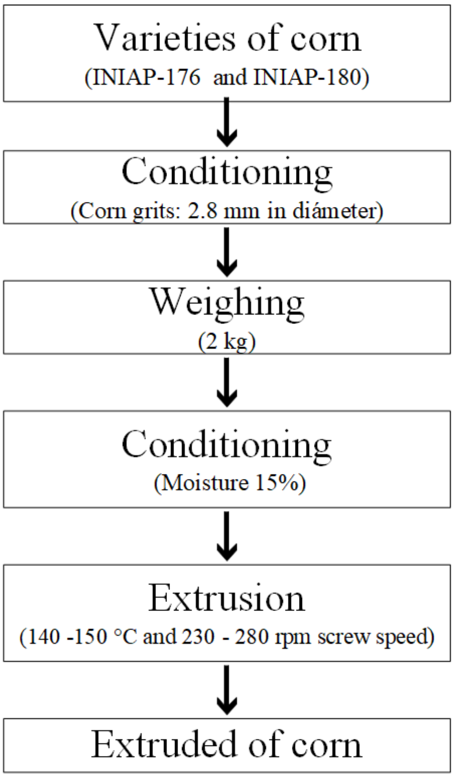

Figure 1. Flowchart for corn grits extrusion.

2.4.2. Total starch

Polarimetric determination of starch content is based on the optical activity of starch. The samples were dissolved with HCl solution. After dissolution, the samples were clarified, filtrated and measured in a polarimeter. The optical rotation of all samples was measured at 20 °C using a sample cell with an optical path length of 200 mm [20].

2.4.3. Functional Properties of extruded products

a) Water absorption index and water solubility index

The water absorption index (WAI) and solubility index (WSI) of the studied extrudates were determined by the method of Anderson et al. [21]. 2.50 g of ground sample was placed in a centrifuge tube with 30 mL of distilled water at 30 °C. Samples were incubated in a Sybron

Thermolyne shaking bath, (Dubuque, Lowa, USA) for 30 min, then shaken in a Damon/IEC division centrifuge (Needham Hts., MA, USA) for 5 min. The supernatant was separated, placed in Petri dishes, and dried for 4 hours at 90 °C. The weight of the gel was heavy. The results were expressed as the average of 3 observations. WAI and WSI were calculated using the following formulas.

$$\text{WAI (g/g)} = \frac{gel\ weigth}{sample\ weigth} \text{ x } 100 \quad (2)$$

$$\text{WSI (\%)} = \frac{Weigth\ of\ solubles}{Sample\ weigth} \text{ x } 100 \quad (3)$$

b) Expansion index (EI)

A Mitutoyo digital caliper (Sao Paulo, Brazil) was used to evaluate the expansion index and 50 observations were made per formulation. Expansion index (EI) is the ratio between the cross-sectional area of the extruded an the died (nozzle). EI was calculated using the following formula [22].

$$EI = \frac{extrudate\ diameter}{die\ diamenter} \quad (4)$$

c) Bulk density (BD)

The density of the extrudates was calculated through the dimensions of the samples. The length and diameter of each piece were determined with a Mitutoyo caliper (Sao Paulo, Brazil). Then, each of the samples was weighed on a balance [23]. The apparent density was calculated using the following formula.

$$\text{BD} = \frac{m}{\pi(\frac{d}{2})^2\ L} \quad (5)$$

where *BD* is bulk density (g/cm^3), *m* is the sample weight, *d* is the diameter (cm) and *L* is the length of the extrudates.

2.4.4. Instrumental texture analysis

A TA-XT2i Texturometer was used, Stable Micro Systems Ltd, Godalming, with a load of 5N; The following tests were carried out:

- Puncture test: with a 5 mm diameter stainless steel cylindrical probe. At a test speed of 2 mm/s and a perforation of 50% of the thickness of the sample (10 mm in diameter). The maximum force obtained in newtons was taken as the result of the test [24].
- Compression test: A 25 mm diameter cylindrical probe was used, with a test speed of 2 mm/s and a compression of 50% of the height of the sample. The force required to compress 50% of the height of the sample (10 mm in diameter), in newtons, was taken as the test result.
- Shear test with guillotine probe: with a guillotine cutting blade, at a test speed of 2 mm/s. The cut was made perpendicular to the main axis of the product until it was completely broken. The maximum force obtained, in newtons, was taken as the result of the test.
- Cutting test fine kerf blade: with a test speed of 2 mm/s. The cut was made perpendicular to the

main axis of the product until it was completely broken. The maximum force obtained, in newtons, was taken as the result of the test.

- Fine cutting blade cutting test: With a test speed of 2 mm/s, the cut was made perpendicular to the main axis of the product until it completely broke. The maximum force obtained, in newtons, was taken as the result of the test. All the analyses were performed with ten observations.

2.4.5. Sensory acceptability analysis

For the evaluation of sensory quality regarding color, odor, texture and taste, a sensory acceptability test was conducted with 27 panelists (14 women and 13 men, between the ages of 20 and 40) who work at the Santa Catalina Experimental Station, INIAP. The extruded product samples were placed on coded white plastic plates and evaluated randomly. A 7-point hedonic scale was used: (1-disliked extremely, 2-much disliked, 3-disliked, 4-liked and did not like, 5-liked, 6-a lot, 7-liked extremely) [25].

2.5. Statistical analysis

The statistical analysis was performed using the Infostat program (Córdoba, Argentina) [26]. Prior to this, the normal distribution of the data was checked with the Shapiro-Wilks goodness-of-fit test. Also, t-student test was applied, which allowed verifying that there is statistical significance in all the analytes under study, proximal composition of corn grits (INIAP-176 y INIAP-180). The other data were subjected to ANOVA analysis using Tukey's 95% test to establish differences between treatments and the least significant difference (LSD) test at 5% for factors. For non-parametric variables (color, smell, flavor and texture), the Friedman test was used at a 5% significance level using the chi-squared statistic. The data were expressed as mean ± SD (standard deviation).

3. Results and discussion

3.1. The chemical composition of corn grits and extruded products.

Table 1 shows the proximate composition of corn grits. Statical analysis (Student’s test) confirmed significant differences between INIAP-176 and INIAP-180 grits. The moisture content of these varieties falls within the range (14%) established according to the NTE INEN: 2 051: 2013 standard, applied to "Cereals and Legumes, Ground Corn, Semolina, Flour, Grits. Requirements" [27]. Regarding the ash percentage, the INIAP-176 corn variety presented a higher content than the INIAP-180 variety. on the other hand, a higher proportion of protein and ether extract were recorded in the INIAP-180 corn varieties. The nitrogen-free extract is the highest component in the corn grits of the two species. However, the corn grits used in this study to obtain the extruded products meet the requirements specified in the NTE INEN: 2 051: 2013 standard, and these results are like studies reported by Yánez 2013 [28,29]. Total starch of INIAP-180 corn presented a higher than INIAP-176 variety. However, the chemical composition differs from other studies. The genetic conditions, farming activities and environmental could influence the chemical composition of corn [30].

Table 1. Comparison of chemical composition of corn grits (INIAP-176 y INIAP-180) (g/100 g dry weight of the sample).

Parameters	INIAP-176	INIAP-180
Moisture	12.00 ± 1.41[a]	11.07 ± 0.05[a]
Ash	1.33 ± 0.94[a]	0.80 ± 0.10[b]
Protein	9.61 ± 0.17[b]	10.80 ± 0.34[a]
Ether extract	5.33 ± 0.01[b]	5.40 ± 0.10[a]
Crude fiber	2.03 ± 0.01[b]	3.16 ± 0.05[a]
Nitrogen free extract	81.7 ± 0.84[a]	79.84 ± 0.44[b]
Total starch	57.69 ± 1.22[b]	62.92 ± 0.77[a]

Notes: Mean ± standard deviation (n = 3); *Values associated with different letters within a column are significantly different ($p < 0.05\%$).

Regarding the effect of the extrusion process on the chemical composition (Table 2), statistical analysis confirms the existence of significant differences ($p < 0.05$) among extruded samples. The process caused a reduction in moisture content. The values obtained ranged from 3.20–2.40 g/100g dry basis. The low moisture content of the products is related to the evaporation of water during the extrusion process [12]. Increasing the screw speed allowed for an increase in temperature and a decrease in product moisture. Similar results were observed in other studies of extruded snacks, determining those high temperatures generate greater heating of water, causing moisture loss in the extruded due to evaporation [31,32].

The ash content remained in a range between 0.72 to 0.51 (g/100g dry basis). However, the effect of extrusion decreased the values of this analyte compared to corn grits. Other studies have reported higher ash contents and the incorporation of other raw materials different from corn (such as lupine, potato, wheat and lentil) favored the increase of minerals [33,34].

The effect of variety and temperature significantly influenced the protein content of the extruded product compared to grits. The extruded products from the INIAP-176 corn variety treatments, subjected to a temperature of 140 °C, reached a higher value of this component compared to extrusion at 150 °C. Protein loses its nutritional value when subjected to high temperatures due to denaturation and inactivation of the hydrolytic enzymes present in corn grits [35]. However, the extrusion process facilities the interaction between protein and starch [36] The starch-protein interaction inhibits starch degradation and reduces water-holding capacity, decreasing the amount of protein that can be solubilized [37]. In the case of ether extract, the reduction in the level of this compound can also be attributed to the formation of complexes between amylose-protein [12]. Other studies conducted on soy extrudates agree that the effect of high temperatures and screw speed influences the decrease in fat content [38].

Regarding crude fiber, the highest content was recorded when applying a temperature of 150 °C and a speed of 180 rpm in the INIAP-176 corn variety (1.76 g/100g dry basis), followed by the INIAP-180 variety under the same extrusion conditions (1.68 g/100g dry basis). However, a decrease in this compound was observed in the corn grits. This variation could depend on the intensity of shear stress in the extruder [39]. As for the nitrogen-free extract (NFE), the extruded snacks presented values ranging from 89.11–88.00 (g/100g dry basis).

The carbohydrate content increased as the moisture decreased and the equipment temperature increased. The extrusion process caused increase in the starch content. The extrusion conditions (high temperatures and pressure) cause the breaking of the amylose and amylopectin chains, generating modification in the crystallinity and greater starch gelatinization, which could produce an increase in the starch [34,38]. Additionally, the degree of gelatinization influences the susceptibility of processed starch to enzymatic digestion. The greater the change in relation to its native structure, the higher the degree of digestion obtained, and the extrusion is responsible for the increase in the glycemic index [36,40]. However, these values are lower compared to other studies, where the starch content is in the range of 76–79%. Some reports showed that corn starch with high amylose (0–50%) content could obtain better expansion and texture characteristics [41].

Table 2. Chemical composition of corn extrudates (g/100 g dry weight of the sample).

	Moisture	Ash	Protein	Ether extract	Crude Fiber	NFC	Starch
T1	2.97 ± 0.05^{b}	0.57 ± 0.01^{d}	8.96 ± 0.17^{ab}	0.56 ± 0.00^{ab}	1.41 ± 0.04^{d}	88.51 ± 0.33^{bc}	64.00 ± 0.20^{bc}
T2	2.45 ± 0.06^{a}	0.70 ± 0.01^{b}	9.06 ± 0.10^{a}	0.76 ± 0.02^{e}	1.49 ± 0.04^{cd}	88.00 ± 0.27^{c}	64.85 ± 0.17^{b}
T3	2.50 ± 0.16^{a}	0.51 ± 0.01^{f}	8.27 ± 0.38^{c}	0.56 ± 0.01^{ab}	1.55 ± 0.08^{bc}	89.11 ± 0.36^{a}	63.86 ± 0.33^{bc}
T4	2.50 ± 0.15^{a}	0.72 ± 0.01^{a}	8.22 ± 0.2^{c}	0.62 ± 0.00^{cd}	1.76 ± 0.07^{a}	88.69 ± 0.05^{ab}	63.17 ± 0.54^{c}
T5	3.20 ± 0.10^{b}	0.64 ± 0.00^{c}	8.45 ± 0.12^{bc}	0.59 ± 0.01^{bc}	1.41 ± 0.04^{d}	88.91 ± 0.08^{ab}	67.76 ± 0.40^{a}
T6	2.40 ± 0.03^{a}	0.53 ± 0.00^{e}	8.55 ± 0.11^{abc}	0.61 ± 0.01^{cd}	1.46 ± 0.02^{cd}	88.83 ± 0.13^{ab}	68.03 ± 0.34^{a}
T7	2.60 ± 0.04^{a}	0.69 ± 0.00^{b}	8.45 ± 0.40^{bc}	0.65 ± 0.02^{d}	1.59 ± 0.01^{bc}	88.62 ± 0.39^{abc}	67.15 ± 0.29^{a}
T8	2.46 ± 0.15^{a}	0.56 ± 0.00^{d}	8.41 ± 0.01^{bc}	0.52 ± 0.03^{a}	1.68 ± 0.04^{ab}	88.83 ± 0.09^{ab}	68.13 ± 0.52^{a}
Variety (V)	21.39**	21.22**	5.89*	60.80**	5.75*	41.04**	626.75**
Temperature (T)	670.00**	124.71**	7.13*	0.55^{ns}	123.14**	285.49**	14.79**
Screw speed (S)	227.86**	8.82**	0.00^{ns}	15.70**	46.53**	61.96**	5.44*
Interaction VT	22.01**	8.43*	7.03*	9.82**	18.35**	29.66**	4.70*
Interaction VS	59.12**	992.88**	0.39^{ns}	53.24**	0.59^{ns}	51.65**	3.30*
Interaction TS	71.43**	0.41^{ns}	5.53*	138.31**	1.60^{ns}	0.95**	1.83*
Interaction VTS	38.16**	95.97**	0.00^{ns}	1.98**	7.57*	8.74^{ns}	13.64*
CV	3.33	2.07	2.59	3.29	3.33	0.23	0.56

Notes: Mean ± standard deviation (n = 3), NFC: Nitrogen free extract, CV: coefficient of variation, ** highly significant, * significant, ns no significant. T1: INIAP-176, 140 °C, 230 rpm; T2: INIAP-176, 140 °C, 280 rpm; T3: INIAP-176, 150 °C, 230 rpm; T4: INIAP-176, 150 °C, 280 rpm; T5: INIAP-180, 140 °C, 230 rpm; T6: INIAP-180, 140 °C, 280rpm; T7: INIAP-180, 150 °C, 230 rpm; T8: INIAP-180, 150 °C, 280 rpm.

3.2. The functional properties of extruded products

Table 3 shows the functional properties of extruded corn. The water absorption index (WAI) indicates the capacity to absorb water into the molecules, that is, the degree of swelling of the starch granules. The solubility index (WSI) determines the dextrinization of the starch and allows the degradation of these molecules to be determined [42,43]. In the case of WAI, the analysis of variance showed that screw speed and variety have a highly significant effect on this variable. WAI of the extruded corn ranged from 5.62–5.09 g/g. In the INIAP-176 variety, applying a temperature of 150 °C increased water absorption. However, in the INIAP-140 corn at a temperature of 150 °C and a screw speed of 280 rpm, this index decreased due to the increase in the ether extract, protein and fiber contents in the corn grits of the INIAP-140 variety. Some studies suggest that fat acts as a lubricant, which leads to a decrease in shear force, reduces the degree of gelatinization and results in lower WAI values [10]. Similar results are also shown in extruded corn with the incorporation of sprouted chickpeas (5.05–4.77 g/g).

The analysis of variance showed that WSI, variety and screw speed have a greater effect than relation temperature and interactions. From the values of WSI of extruded corn ranged from 0.17–0.12 g/100g, it can be observed that the solubility index decreases when using INIAP-176 corn. In research of extruded corn with the addition of sprouted chickpeas, WSI was higher (15.60–10.90 g/100g) relative to this study [12]. The alterations that starch undergoes during the milling process and the conditions in the extrusion process could have influenced these results [44].

Regarding the expansion index, values remained in a range between 5.72%–4.99%. The effect of temperature influenced the increase of the expansion index since it increases the degree of starch gelatinization [45]. Another factor that influences is the variety of corn; when using the INIAP-180 corn that has a higher amount of protein and fiber, the expansion index decreases. Fiber molecules break the structure of the melted mass in the extruder, delaying the gelatinization of starch and preventing the elastic deformation of the mass. Therefore, the expansion of the extruded product decreases [44,46]. However, low expansion indices affect the texture and durability of the product. Research conducted on extruded products incorporating quinoa, lupine and chickpeas reports low indices, as these raw materials have a higher amount of protein compared to corn [12,32]. When using raw materials that contain a higher proportion of starch, the expansion process generates structures with a greater number of pores and sizes that favor this process [47].

The variety, temperature and screw speed have significant effect. The apparent density of the extruded products ranges from 0.16–0.22 g/cm^3, and there is an inverse relationship with the expansion index. The ingredients, temperature and screw speed of the extruder affect these results. Extruded snacks made with the INIAP-180 corn variety show a partial increase in bulk density due to a higher content of protein and fiber, which reduces water absorption, resulting in compact and hard expanded products [47,48].

3.3. Instrumental texture

The texture of an extruded snack is a fundamental characteristic, with crispness being the most desirable attribute in these products [49]. Compression and puncture tests allow compressing and fracturing of the food, a process like that of human molar teeth. Cutting tests break or fracture the product like the function of incisor teeth [50]. In this research, it was determined that there were statistically significant effects of temperature, screw speed and corn variety factors on the texture tests performed, except for the compression attribute. The results are shown in Figure 2.

About the compression test, higher values were recorded compared to the puncture test, possibly due to a greater contact area of the compression probe compared to the puncture test of the extrudate. Similar results were reported in studies carried out on low temperature nixtamalized corn extrudates, where it was established that the type of corn, grain hardness, water absorption and degree of starch gelatinization directly influence texture attributes [44]. Additionally, differences in texture characteristics can be attributed to the addition of raw materials that have a higher proportion of protein and fat than corn [33].

Table 3. Functional properties of corn extrudates.

Treatments	WAI (g/g)	WSI (g/ 100g)	Expansion index (%)	Apparent density (g/cm^3)
T1	5.09 ± 0.01^a	0.16 ± 0.01^{ab}	5.02 ± 0.08 ^{c}	0.22 ± 0.00 ^{b}
T2	5.02 ± 0.01^a	0.16 ± 0.01^{ab}	5.43 ± 0.05^{ab}	0.18 ± 0.01^a
T3	5.59 ± 0.04 ^{c}	0.14 ± 0.01 ^{bc}	5.72 ± 0.23^a	0.17 ± 0.00^a
T4	5.62 ± 0.06 ^{c}	0.12 ± 0.01 ^{c}	5.70 ± 0.02^a	0.16 ± 0.00^a
T5	5.40 ± 0.17 ^{bc}	0.12 ± 0.02 ^{c}	5.10 ± 0.11 ^{bc}	0.22 ± 0.01^b
T6	5.51 ± 0.10 ^{c}	0.17 ± 0.01^a	4.99 ± 0.16 ^{c}	0.19 ± 0.01^a
T7	5.17 ± 0.02 ^{ab}	0.14 ± 0.01 ^{bc}	5.54 ± 0.04^a	0.21 ± 0.01^b
T8	5.54 ± 0.17 ^{c}	0.14 ± 0.01 ^{bc}	5.46 ± 0.17^{ab}	0.22 ± 0.01^b
Variety (V)	18.70**	10.52**	15.99**	24.83**
Temperature (T)	4.07^{ns}	0.99^{ns}	13.75**	49.93**
Screw speed (S)	32.94**	17.71**	80.63**	14.90**
Interaction VT	7.93*	7.09*	1.06^{ns}	30.39**
Interaction VS	68.76**	9.19**	1.06^{ns}	43.60**
Interaction TS	11.08**	20.40**	7.88*	1.60^{ns}
Interaction VTS	5.11*	12.81**	3.46^{ns}	33.15**
CV	1.77	7.33	2.39	4.41

Notes: Mean ± standard deviation (n = 3), CV: coefficient of variation, ** highly significant, * significant, ns no significant. T1: INIAP-176, 140 °C, 230 rpm; T2: INIAP-176, 140 °C, 280 rpm; T3: INIAP-176, 150 °C, 230 rpm; T4: INIAP-176, 150 °C, 280 rpm; T5: INIAP-180, 140 °C, 230 rpm; T6: INIAP-180, 140 °C, 280rpm; T7: INIAP-180, 150 °C, 230 rpm; T8: INIAP-180, 150 °C, 280 rpm.

3.4. Sensory acceptability

In the following table, the sensory characteristics (color, smell, taste and texture) of the studied products are observed. In the case of texture attribute, the panelist evaluated the crispness when biting into snack of extruded samples. Regarding the color attribute, panelists have a greater preference for treatments T2 (INIAP-176, temperature 140 °C and screw speed of 230 rpm) and T7 (INIAP-180 maize variety, temperature 150 °C and screw speed of 230 rpm). On the other hand, the treatment that achieved the highest score for the smell attribute was treatment 6 (INIAP-180 variety, temperature of 140 °C and screw speed of 280 rpm).

In the case of texture, panelists established that treatment 8 (INIAP-180 variety, temperature of 150 °C and screw speed of 280 ppm) maintains adequate crispness characteristics in relation to the other treatments. In terms of flavor, treatments T2 and T8 received higher scores. Overall, the evaluated treatments received an acceptable rating from the panelists. Also, the moisture content of the extrudate can affects sensory acceptability, especially the texture [51].

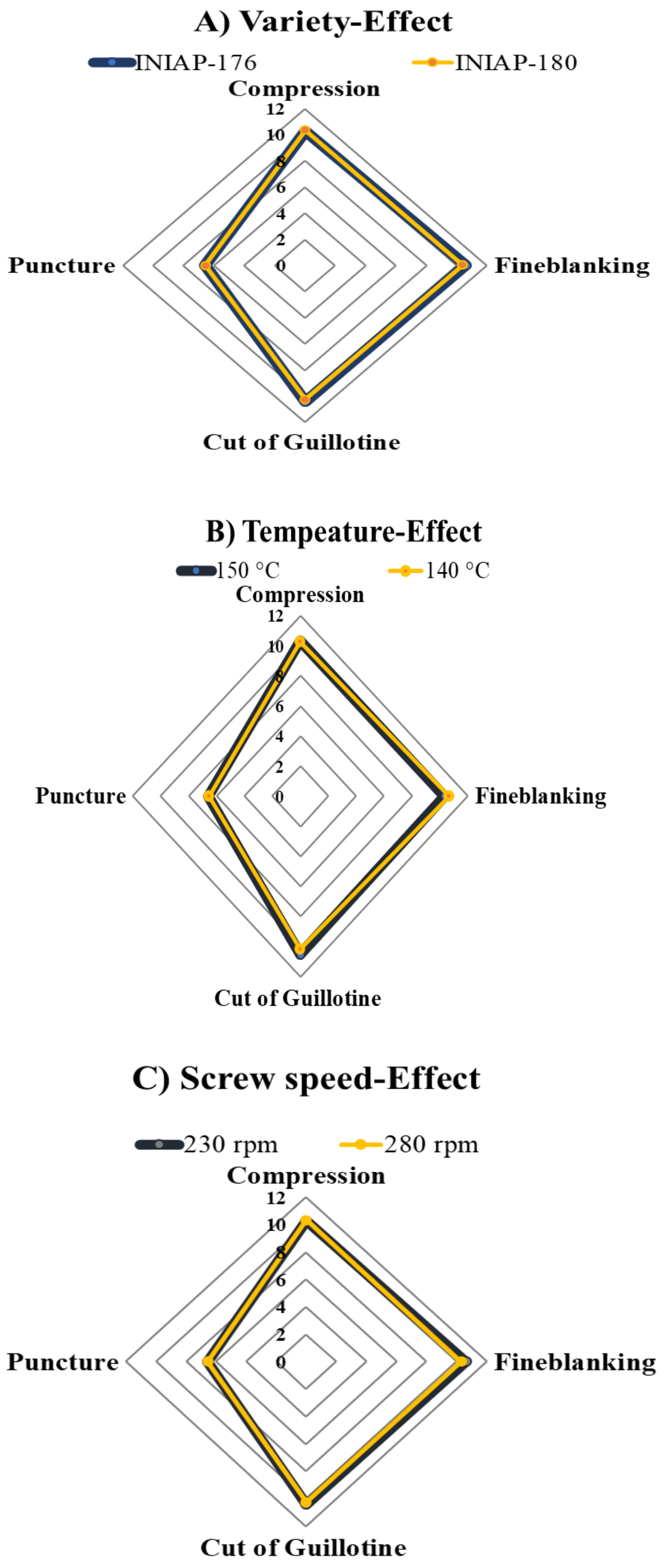

Figure 2. Textural attributes of corn extruded.

Notes: Results expressed in Newtons (N)

Table 4. Sensory acceptability of corn extrudates.

Treatments	Color	Smell	Texture	Taste
T1	3.70 ± 0.82[a]	4.20 ± 0.91[a]	2.80 ± 0.42[a]	3.30 ± 0.82[ab]
T2	3.80 ± 1.03[a]	4.10 ± 0.99[a]	3.10 ± 0.87[a]	3.80 ± 0.91[a]
T3	3.60 ± 0.69[a]	4.30 ± 0.94[a]	2.80 ± 0.63[a]	3.50 ± 1.26[ab]
T4	3.20 ± 0.42[a]	4.30 ± 0.82[a]	3.10 ± 0.56[a]	3.50 ± 1.08[ab]
T5	3.70 ± 1.05[a]	4.10 ± 0.56[a]	3.20 ± 0.78[a]	3.10 ± 1.87[b]
T6	3.30 ± 0.48[a]	4.70 ± 0.31[a]	2.70 ± 0.67[a]	3.80 ± 1.03[a]
T7	3.80 ± 1.03[a]	4.10 ± 0.87[a]	2.70 ± 0.94[a]	3.30 ± 1.05[ab]
T8	3.10 ± 0.99[a]	4.10 ± 0.81[a]	3.30 ± 0.67[a]	3.40 ± 0.84[ab]
Fr	19,442**	19,638**	19,006**	18,986**

Notes: Mean ± standard deviation (n = 30). Fr: The calculated non-parametric Friedman test value; **: highly significant (X2, p ≤ 0.01). T1: INIAP-176, 140 °C, 230 rpm; T2: INIAP-176, 140 °C, 280 rpm; T3: INIAP-176, 150 °C, 230 rpm; T4: INIAP-176, 150 °C, 280 rpm; T5: INIAP-180, 140 °C, 230 rpm; T6: INIAP-180, 140 °C, 280rpm; T7: INIAP-180, 150 °C, 230 rpm; T8: INIAP-180, 150 °C, 280 rpm.

4. Conclusion

The results of this research allowed determine that the processing conditions (corn variety, extruder temperature and screw speed) have a significant effect on the evaluated physicochemical parameters. Corn extrudates with low moisture content and an average protein content of 8.54 g/100 g dry basis were obtained. The values of ether extract and fiber in extruded samples decreased compared to corn grits. Besides, the increase in temperature and screw speed affected the increase of expansion index, but the apparent density decreases in the extruded samples. The instrumental texture profile determinate significant effects of temperature, screw speed, and corn variety factors on the texture factors (fineblanking, cut of guillotine and puncture) except for the compression attribute. However, the use of the INIAP-176 and INIAP-180 corn varieties can serve as raw material for obtaining these products since they can achieve adequate acceptability among consumers.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of interest

All authors declare that have no conflict of interest.

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