

TEXTURE AND QUALITY OF ELOTES OCCIDENTALES MAIZE GRAIN FOR POZOLE PREPARATION

TEXTURA Y CALIDAD DEL GRANO DE MAÍZ ELOTES OCCIDENTALES PARA PREPARACIÓN DE POZOLE

Norma Santiago-López^{1*}, J. Jesús García-Zavala¹, Grisel I. Cruz-Santiago², Arlet D. Cruz-Santiago²,
Filogonio J. Hernández-Guzmán³, Javier Suárez-Espinosa¹ and Benjamín Ramírez-Wong⁴

¹Colegio de Postgraduados, Campus Montecillo, Montecillo, Texcoco, Estado de México, México. ²Escuela General Manuel Ávila Camacho, Texcoco, Estado de México, México. ³Universidad Autónoma Chapingo, Chapingo, Estado de México, México. ⁴Universidad de Sonora, Hermosillo, Sonora, México.

*Corresponding author (nsantiago@colpos.mx)

SUMMARY

Pozole is an important food in Mexico which is made from processed corn grain. During this process, the physicochemical and structural properties of grain are modified. The objective of this study was to determine the physical, chemical and texture quality of grain, nixtamal, and pozole of 12 maize genotypes of the Mexican race Elotes Occidentales and two controls (Ancho and Cacahuacintle) grown in two locations in the Valley of Mexico. The raw material was cooked in water with 1 % lime at boiling temperature for 20 min and was soaked for 14 h to obtain nixtamal. The variables recorded for grain were: grain dimensions, weight of 1000 kernels, color, protein content and texture, and for nixtamal the traits studied were: grain size nixtamalized dimensions, color, moisture, protein content, texture, volume and pH. Popping time, popping expansion volume, moisture content and texture properties of pozole were determined. The analysis of variance detected significant differences ($P \leq 0.05$) between treatments for the physical, chemical and texture properties of the grain, nixtamal and pozole; in addition, significant differences were detected for popping time and pozole expansion volume. For texture, the evaluated genotypes were 10 % softer compared to the control Ancho.

Index words: *Zea mays* L, hardness, environment, local races, nixtamal, pozole.

RESUMEN

El pozole es un alimento importante en México a base de grano de maíz procesado. Durante este proceso se modifican las propiedades fisicoquímicas y estructurales del grano. El objetivo de este estudio fue determinar la calidad física, química y de textura del grano, nixtamal y pozole de 12 genotipos de maíz de la raza mexicana Elotes Occidentales y dos controles (Ancho y Cacahuacintle) cultivados en dos localidades del Valle de México. La materia prima se cocinó en agua con 1 % de cal a temperatura de ebullición durante 20 min y fue remojada durante 14 h para obtener el nixtamal. Las variables registradas para grano fueron: dimensiones del grano, el peso de 1000 granos, color, contenido de proteína y textura; y para el nixtamal las variables estudiadas fueron: dimensiones del grano nixtamalizado, color, contenido de humedad y proteína, textura, volumen y pH. Se determinaron el tiempo de reventado, el volumen de expansión del grano, el contenido de humedad y las propiedades texturales del pozole. El análisis de varianza detectó diferencias significativas ($P \leq 0,05$) entre tratamientos para las variables físicas, químicas

y de textura de maíz, nixtamal y pozole; además, se detectaron diferencias significativas ($P \leq 0,05$) entre los tratamientos para tiempo de reventado y volumen de expansión del pozole. En textura, los genotipos evaluados fueron 10 % más suaves en comparación con el control Ancho.

Palabras clave: *Zea mays* L, dureza, medio ambiente, nixtamal, pozole, razas locales.

INTRODUCTION

Knowledge about the physical, chemical and texture characteristics of maize grains (*Zea mays* L.) and their quality for pozole preparation is scarce; however, this aspect is relevant because more than 60 % of native maize is used for human consumption in Mexico (León-Murillo *et al.*, 2021), and countless research focus on specific studies of dough and tortilla quality. Grain texture in cereals, legumes and oilseeds is a concept that is becoming increasingly important in breeding programs since the physical, chemical and texture characteristics of maize grain can vary widely depending on the variety employed (Jamanca-Gonzales *et al.*, 2024). These characteristics can be improved by changes in agricultural practices (Agama-Acevedo *et al.*, 2011) and through plant breeding. Sanchez *et al.* (2000) described 59 maize races native to Mexico, many of which are used by breeders for agronomic, morphological and genetic studies.

The few studies on product quality (tortilla, dough and pozole) have focused mainly on local and specific materials, without prior agronomic quality aspects (Ramírez-Vega *et al.* 2022). In addition, studies on the physical characteristics of grain (hardness, test weight, size, and the weight of a thousand grains) and their relationship with the end use in the Elotes Occidentales race cultivated in the high valleys of Mexico are still scarce (Ballesteros *et al.*, 2019).

At least 10 native races have been identified, of those described by Sanchez *et al.* (2000), for production of pozole in various regions of Mexico. These races are characterized by having large grains and a high proportion of soft endosperm in the caryopsis. Among these races, Cacahuacintle is the most commonly used, as it shows a white color, with a floury texture and large-sized grain (Bonifacio *et al.*, 2005). Cacahuacintle is produced only in small portions of the highlands in central Mexico, at altitudes between 2600 and 2900 masl; therefore, it is insufficient to meet the demand of the domestic market (Arellano *et al.*, 2010).

Pozole is a pre-Hispanic dish that consists of cooking grains after nixtamalization. The quality of pozole in a production chain starts from the cultivation of grain, associated both with its physical constitution, which determines the texture evaluated as hardness, and its chemical composition that defines the nutritional value and technological properties (González, 2018). Demand for nixtamalized corn is another feature that has become relevant at an industrial level, which has motivated researchers to study grain quality characteristics in both breeding programs and the industrial process of nixtamalized corn products (Scott *et al.*, 2019).

The dough and tortilla industry is an area where quality parameters have become more technical, among which the texture of nixtamal stands out, represented by the grain hardness. The importance of measuring this trait in nixtamal is because it is the first product obtained in the tortilla production process, and it is used to predict the quality of dough and tortilla as starch in the nixtamalization process exhibits structural and functional changes that not only depend on grain characteristics, but also on processing conditions such as the moisture content of nixtamal, pH of nejayote and solids loss. This has a significant impact on water absorption and thus on the texture of nixtamal (Ibarra-Mendivil *et al.*, 2008).

Textural properties in food are defined by the physical structural characteristics of the material and their relationship with deformation, disintegration and flow due to the application of a force. In cereals, they are associated with the degree of compaction of starch granules and the presence of proteins surrounding them. Therefore, for quality analysis, the texture should be the main parameter, as it has a significant effect on cooking time and sensory acceptance by consumers (Blandino *et al.*, 2010).

The most studied parameters in pozole quality are the solid content in nejayote (the remaining liquid after alkaline cooking), yield, expansion volume, moisture content, hardness, percentages of heads (pedicels) and popped

grains, popping time, cooking broth viscosity and color. It has been observed that the grain with greater whiteness is more appreciated by consumers, so the agroindustry prefers to develop a product with these characteristics, in the absence of other available alternatives (Vázquez and Santiago, 2013). The objective of this study was to evaluate 12 genotypes of pigmented Elotes Occidentales maize race on the physical, chemical and texture characteristics of the grain as well as the quality of nixtamal and pozole.

MATERIALS AND METHODS

Raw material germplasm source

Twelve genotypes of the Mexican maize race Elotes Occidentales were evaluated. Such genotypes were labeled as EOM-1, EOM-2, EOM-3, EOM-4, EOM-5, EOM-6, EOM-7, EOM-8, EOM-9, EOM-10, EOM-11 and EOM-12. Two commercial local genotypes were used as a control: Ancho and Cacahuacintle. The 12 genotypes of Elotes Occidentales were collected in the state of Guanajuato, Mexico, at 1700 masl. These genotypes were planted in the 2023 growing season under rainfed conditions at two experimental sites: Colegio de Postgraduados (CP) and Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP), both in the municipality of Texcoco, State of Mexico, Mexico, which has a temperate climate with an average annual temperature of 15 °C, annual rainfall of 645 mm, at an altitude of 2,250 masl. Planting was carried out in the Summer growing season, with a 20-day interval between locations under a randomized complete block experimental design with three replications. At harvest, all maize ears of each genotype were shelled and a 2 kg samples of grain from each experimental unit was taken and stored in a cold room at 4 °C for quality studies.

Variables evaluated

The grain length, width and thickness were measured in mm across all genotypes in 20 grains of maize with a digital vernier (Model CD6" C Mitutoyo Corporation, Kanawa, Japan). The weight of one thousand kernels (TKW) was determined using 1000 healthy maize kernels that were weighed on an analytical balance (Sartorius Research R300S, Göttingen, Germany). Grain color was measured with a colorimeter (Hunter LabMiniScanXE Plus® Model 45/0-L, Reston, Virginia, USA), and the parameters *L*, *a*, and *b* were recorded and performed in triplicate for each genotype. The moisture content for all nixtamalized samples of the 12 genotypes and controls was determined by Method 44-19.01 of the AACC International (2010), and a forced-air convection furnace (Blue M, model OV - 4902-A, White Deer, Pennsylvania, USA) at 105°C for 72 h of drying. The total protein content (%) on a dry basis

was determined by Method 46-16 of AACC International (2010), using a nitrogen determinator (model FP-528, LECO Corporation, Leco, St. Joseph, Michigan, USA) and a conversion factor of $N \times 7$.

Nixtamalization and associated evaluation

Samples of maize grains (100 g) were nixtamalized in 300 mL of water and 1 % food-grade lime (Nixtocal Calhida®, Sonora, Mexico). The maize grains were boiled at 95 °C for 20 min according to the procedure of Ramírez-Wong *et al.* (1993). The cooked corn was left to stand for 14 h at room temperature (25 °C) to obtain nixtamal. Subsequently, the nejayote cooking broth was retrieved to perform analytical evaluations.

The dimensions of the nixtamalized grains were determined as in the raw material, measuring the length, width and thickness of 20 whole nixtamalized grains of each previously washed sample. The moisture content of the nixtamalized samples was determined as in the raw samples. The total protein content (%) on a dry basis was determined by the method and technique previously described. The texture of nixtamal was measured through the procedure reported by Ibarra-Mendivil *et al.* (2008) with modifications, using a texture analyzer (C920, TA-XT plus Stable Micro Systems, Surrey, UK) equipped with a 2 mm diameter probe (p/2) and a metal platform with an orifice; 10 nixtamal grains were drilled individually on the germ side, at the central part of the endosperm at a speed of 1 mm s⁻¹ until they broke through the cooked grain. The texture of nixtamal was reported as hardness (kPa). The color was determined in nixtamalized grain as in raw material, and in previously washed whole grains. The evaluated parameters were *L*, *a* and *b*, which were measured three times in each genotype

The pH was measured in nejayote following the Method 02-52.01 of AACC International (2010), with a potentiometer (Corning model 2000 Plus. Corning, New York, USA) calibrated with buffer solutions of pH 7 and pH 10.

Obtention and evaluation of pozole

Samples consisting of 180 maize grains were poured into 360 mL of water and 1 % lime for nixtamalization under the conditions mentioned in the previous paragraph. The quality of pozole was determined by the popping time of nixtamal, which according to Robles-Ozuna *et al.* (2016) "popping is the final boiling after the nixtamal in which it swells and explodes until it acquires a shape similar to that of a flower".

The popping time was measured empirically by establishing annealing time ranges (40, 60 or 80 min) where the evaluated genotypes could obtain 60% of popped grains (popping time). Once the ranges were established, the nixtamal samples were washed with tap water to remove pericarp and nejayote residues. Samples were then divided into three subsamples of 60 grains, poured into 160 mL of water each and boiled in covered flasks for 40, 60 or 80 min, respectively. After the annealing times, the samples were left to cool at room temperature. Subsequently, the number of popped grains from each sample was counted. Popping time was determined by linear regression when 60 % of the grains popped. The following linear equation was used:

$$Y = b_0 + mx$$

Where: *Y* is the number of popped grains, *x* the popping time, *b*₀ the intercept and *m* the slope

After popping, the expansion volume was determined by measuring each water-free pozole sample into a graduated cylinder and recorded the volume in mL. The moisture content of pozole was quantified at 3 g of the sample placed on trays using the equipment and methods described in the previous section. The pozole texture was measured as the hardness (kPa) registered at the maximum peak of puncture force obtained with the equipment and techniques described for texture measurement in nixtamal.

Statistical analysis

A liner model for a factorial design of two factors (maize genotypes and the environments where genotypes were grown) was used. Analysis of variance was performed for all evaluated traits, and Tukey tests were applied at $P \leq 0.05$ to distinguish significant differences between specific means. The Statistical Analysis System software (SAS Institute, 2009) was employed for the statistical analysis.

RESULTS AND DISCUSSION

Grain measurements

Size, weight and color of the grain are important properties for food maize classification. The traits evaluated for the physical characteristics were grain dimensions (length, width and thickness), weight of one thousand kernels (TWK) and color. Table 1 shows the mean values for each of the evaluated traits. The grain length, width and thickness presented a variation of 1.5 % between genotypes and checks, with average values of 12.3 mm in length, 13.1 mm in width and 5.36 mm in thickness. Genotypes EOM-4, EOM-5, EOM-7, EOM-9 and EOM-12 had the lowest values of these traits; nevertheless, these values exceed those

reported by Figueroa *et al.* (2013), who mentioned that grains of the race Elotes Occidentales are 9.3 mm longh, 11.7 mm wide and 5.8 mm thick. Probably, the gain in grain size is due to the evaluation environment and variation within the race.

The TWK ranged from 708.2 to 469.1 g. The highest value was recorded in genotype EOM-9, while the lowest weight was obtained in EOM-5. This magnitude is indicative that this corn has large grains (100 kernels > 38 g) (Salinas *et al.*, 2010).

The color of the grain presented variation between genotypes, the evaluated materials are pigmented maize. Table 1 shows that the grain color is significantly whiter in Ancho and Cacahuacintle maize ($L = 82.47$) compared to the evaluated materials of Elotes Occidentales with values of $L = 48.32$. For the value *a*, non-significant differences were detected between genotypes, whereas there was a significant difference ($P \leq 0.05$) compared to the controls for the value *b*. The marked color differences between the pigmented EOM genotypes and the white commercial controls reflect the presence of anthocyanin-rich aleurone

layers. The reduction in lightness (*L*) after nixtamalization is consistent with alkaline cooking that promotes pericarp removal and aleurone exposure, a phenomenon widely described in maize nixtamalization chemistry. While lower whiteness may limit some industrial preferences, color is not a major determinant of pozole quality, particularly in regional and traditional markets where texture and popping behavior predominate (Paulsmeyer and Juvik, 2023).

Chemical evaluations

High-protein maize grains increase the food quality for consumers. The evaluated chemical variables were protein and moisture content, which is important as humidity is an indicator of quality (Mex-Álvarez, 2016). Regarding protein content, Table 2 shows that the treatments were similar to the checks on average, and genotypes EOM-6 and EOM-12 had the lowest protein content: 9.85 and 9.87 %, respectively; however, such values are within the ranges reported by Narváz-González *et al.* (2006) for genotypes of pozolero maize. The values presented range from 6.3 to 11.62%, which according to NMX-FF-034/1-SCFI2002 (SCFI, 2002) meet the established parameter that is below

Table 1. Physical characteristics of 14 genotypes of grain for making pozole.

Genotypes	Length	Width (mm)	Thickness	TKW [†] (g)	Color		
					<i>L</i>	<i>a</i>	<i>b</i>
EOM-1	12.6 bc	13.3 bc	5.5 bc	626.7 bc	49.57 bc	15.72 a	8.57 b
EOM-2	12.0 bc	13.9 ab	5.4 bc	632.7 bc	50.15 bc	16.14 a	9.21 b
EOM-3	12.7 abc	13.0 bcde	5.1 bc	590.6 cde	50.55 bc	13.86 a	9.09 b
EOM-4	12.7 abc	12.0 cde	5.1 bc	532.4 def	48.27 bc	14.07 a	8.12 b
EOM-5	12.4 bc	11.7 e	4.8 c	469.1 f	47.03 bc	14.14 a	8.35 b
EOM-6	13.0 ab	14.3 ab	5.4 bc	611.1 cde	48.16 bc	13.85 a	8.58 b
EOM-7	12.5 bc	13.1 bcd	5.3 bc	625.0 c	48.63 bc	13.19 a	8.77 b
EOM-8	12.0 bc	12.0 de	5.1 bc	528.7 ef	40.38 b	12.34 a	8.93 b
EOM-9	11.9 c	13.5 ab	5.7 abc	708.2 ab	49.41 bc	16.92 a	6.31 b
EOM-10	12.0 bc	13.8 ab	5.4 bc	612.9 cd	50.01 bc	13.00 a	8.74 b
EOM-11	12.3 bc	13.0 bcde	5.7 ab	636.5 bc	46.40 bc	13.17 a	9.05 b
EOM-12	11.7 c	13.5 ab	5.4 bc	645.2 bc	51.28 b	13.23 a	8.59 b
Ancho	13.6 a	13.8 ab	5.7 abc	773.7 a	80.83 a	2.01 b	21.17 a
Cacahuacintle	12.8 abc	14.7 a	6.5 a	534.9 def	84.10 a	2.07 b	20.07 a

[†]TKW: thousand kernel weight. Means with the same letter in the columns are not statistically different (Tukey, $P \leq 0.05$).

14 %. The protein content accounts for around 8-10 % of its composition, primarily found in the endosperm, which contains 70 % of the total protein (Muthukumarappan and Swamy, 2018).

Evaluations at nixtamal

The physical characteristics of nixtamalized grains indicate the efficiency of the process from grain to nixtamal transformation. The traits evaluated were the dimensions of nixtamalized grains (length, width and thickness) and color. Table 3 shows the means for each variable. The length, width and thickness of nixtamal presented a variation of 1.5 % between genotypes and the Ancho (control), with mean values of length = 13.8 mm, width = 14.8 mm, and thickness = 6.2 mm; the EOM-11 genotype was superior to Cacahuacintle with values of length = 14.3 mm, width = 15.6mm and thickness = 6.7mm, in addition to being the most uniform genotype in nixtamal size. Mauricio *et al.* (2004) reported significant correlations between grain characteristics and tortilla quality, between water absorption capacity and grain width ($P \leq 0.01$), as

Table 2. Chemical characteristics of grain of 14 maize genotypes for pozole.

Genotype	Moisture content (%)	Protein content (%) [†]
EOM-1	12.83 a	10.09 bcd
EOM-2	14.06 a	10.12 bcd
EOM-3	13.94 a	10.68 ab
EOM-4	13.79 a	10.67 abc
EOM-5	13.13 a	10.13 bcd
EOM-6	12.74 a	9.85 d
EOM-7	13.90 a	10.40 abcd
EOM-8	14.02 a	10.38 abcd
EOM-9	13.79 a	10.10 bcd
EOM-10	13.30 a	10.44 abcd
EOM-11	13.40 a	10.43 abcd
EOM-12	14.44 a	9.87cd
Ancho	13.96 a	10.30 abcd
Cacahuacintle	13.70 a	10.95 a

[†]Dry base. Means with the same letter in the columns are not statistically different (Tukey, $P \leq 0.05$).

well as resistance between cutting, weight of one thousand grains ($P \leq 0.05$), and grain width ($P \leq 0.05$). These authors also reported that grains suitable for producing atole and pozole are characterized by large size and low hardness and test weight.

Nixtamal color was significantly whiter in Ancho and Cacahuacintle with $L^* = 67.17$ compared to the evaluated treatments, which had $L = 38.03$ values. Cooking with lime resulted in nixtamalized grains with approximately 8-12 units less than the original L color for Elotes Occidentales genotypes, and 9-21 units for controls. values of a presented no-significant differences between genotypes; however, there was a decrease of 1 to 3 units in nixtamal compared to the uncooked grain. For the values of b , there was a significant difference ($P \leq 0.05$) between Elotes Occidentales and the controls, but when comparing the nixtamal values with those of unprocessed corn of the pigmented genotypes, there was an increase in color of up to six units, in contrast to the controls, which presented an increase of three units. The foregoing is attributed to the fact that, during the nixtamalization process, the pericarp is lost with lime, so the color in the nixtamal depends on the reaction of the aleurone layer, which is the outer layer remaining after nixtamalization.

Chemical evaluations

The chemical characteristics of the nixtamalized grain determine the yield and quality of nixtamal, dough, tortilla, and pozole. The traits evaluated were moisture and protein content, pH and loss of solids in nejayote. Results showed no significant differences between environments ($P > 0.05$), but significant differences ($P \leq 0.05$) between genotypes. Table 4 shows that moisture content of the nixtamalized grains was 48.96 % on average for Elotes Occidentales, while for Ancho and Cacahuacintle moisture content was 52.22 %. This value is important as high moisture content significantly influences the yield and texture of pozole. The pH and solid loss values of nejayote remained within acceptable limits after the nixtamalization process. The alkaline nature of nejayote (typically pH >10) originates from the use of calcium hydroxide and the solubilization of pericarp components, starch fragments, and other organic and inorganic constituents during cooking and steeping.

Another important variable is protein content of nixtamal. In this study, values of protein content were in agreement with those reported by Narváez-González *et al.* (2006) for genotypes of pozolero maize. Pigmented genotypes were similar to the controls with 9.56 % (dry basis) protein content. These values showed a decrease of 1.2 % in nixtamal compared to the grain without nixtamalization for

Table 3. Physical characteristics of grain corn nixtamal for pozole.

Genotypes	Length (mm)	Width (mm)	Thickness (mm)	Color		
				<i>L</i>	<i>a</i>	<i>b</i>
EOM-1	13.6 bc	13.7 de	6.4 abc	36.89 cd	12.54 a	14.87 b
EOM-2	13.4 bc	15.4 abc	6.3 abc	39.66 c	13.73 a	14.61 b
EOM-3	13.7 bc	14.5 cde	6.3 abc	33.06 d	14.79 a	12.34 b
EOM-4	14.2 abc	13.7 de	5.6 c	38.92 cd	11.85 a	12.54 b
EOM-5	14.2 abc	13.1 e	5.7 c	36.91 cd	13.16 a	14.78 b
EOM-6	13.6 bc	14.7 bcd	6.2 abc	39.30 cd	13.26 a	15.49 b
EOM-7	13.0 c	14.5 cde	6.4 abc	39.72 c	11.89 a	13.04 b
EOM-8	13.4 bc	13.2 e	6.2 abc	34.67 cd	12.47 a	15.43 b
EOM-9	13.3 bc	15.2 abcd	5.7 bc	39.92 c	14.35 a	14.23 b
EOM-10	13.4 bc	15.7 abc	6.0 abc	40.88 c	11.67 a	15.33 b
EOM-11	14.3 ab	15.6 abc	6.7 a	37.04 cd	13.15 a	12.74 b
EOM-12	14.0 bc	15.5 abc	6.4 abc	39.37cd	13.05 a	14.46 b
Ancho	15.3 a	16.1 ab	5.9 abc	71.37 a	0.22 b	23.75 a
Cacahuacintle	13.4 bc	16.7 a	6.6 abc	62.97 b	1.13 b	23.97 a

Means with the same letter in the columns are not statistically different (Tukey, $P \leq 0.05$).

all genotypes; in contrast, genotype EOM-8 did not undergo any changes in protein content from grain to nixtamal.

Significant differences ($P \leq 0.05$) were detected between genotypes, with an average of 0.03 units. EOM-1, 2, 3 and 4 genotypes showed the highest pH values ranging from 12.61 to 12.81. This situation is due to lower water absorption during nixtamalization, which makes the cooking water to remain more alkaline. In contrast, the cooking water of Ancho and Cacahuacintle had a lower pH than the rest of treatments (12.41 and 12.10) because it showed a higher absorption of OH and Ca^{+2} and left more H^+ ions available in the solution (Ruiz-Gutiérrez *et al.*, 2010).

For solids in Nejayote, there were significant differences ($P \leq 0.05$) between genotypes, with an average of 2.9 % for Elotes Occidentales, compared to the control varieties. The values obtained are similar to the solids losses of up to 3.2 % reported by Campechano *et al.* (2012) in a similar study. Likewise, these values were lower than 5 %, specified as the maximum value in the Mexican Standard NMX-FF-034/1-SCFI-2002 (SCFI, 2002).

The total volume of nejayote discarded after nixtamalization averaged 56.1 % of the initial water volume for most genotypes evaluated, except for EOM-8, which presented 61.3 %. Several authors indicated that nejayote solids consist of different chemical compounds such as carbohydrates, cellulose and hemicellulose. These components are released from the grain during nixtamalization and are mainly affected by endosperm hardness, cooking and soaking times, and temperature, which affects the annealing of starch (Campechano *et al.*, 2012).

Hardness, as a characteristic of maize grain texture of corn kernels, is an indirect measure of the chemical compounds and molecular arrangements within the starch granule and corn kernels, which together define the quality of the final product. In this study, the force and tension required to break the nixtamal were measured. A significant difference ($P \leq 0.05$) was observed between genotypes (Figure 1). The genotype with the highest value of texture was Ancho (113.87 kPa). The pigmented genotypes presented intermediate values relative to the controls, and EOM-6, EOM-9 and EOM-10 were the genotypes that required the lowest force, 94.04 kPa on average for drilling

Table 4. Chemical characteristics of nixtamaled grains of 14 genotypes maize for pozole.

Genotypes	MCN [†]	PCN ^{**}	Solid loss	pH	Nejayote volume (mL)
	(%)				
EOM-1	49.05 b	9.14 b	2.64 d	12.81 a	167
EOM-2	48.61 b	9.30 b	2.83 bcd	12.76 ab	164
EOM-3	48.99 b	9.81 ab	3.56 a	12.74 ab	169
EOM-4	49.07 b	9.61 ab	3.02 abcd	12.71 abc	167
EOM-5	50.01 b	9.43 b	3.31 ab	12.66 abcd	175
EOM-6	48.38 b	8.97 b	3.26 abc	12.63 abcd	175
EOM-7	49.03 b	9.63 ab	2.82 bcd	12.53 abcd	160
EOM-8	48.04 b	10.34 a	2.71 dc	12.51 bcd	184
EOM-9	48.69 b	9.54 ab	2.66 dc	12.48 bcd	167
EOM-10	51.12 b	9.57 ab	2.93 bcd	12.44 cd	175
EOM-11	47.34 b	9.78 ab	3.06 abcd	12.44 cd	166
EOM-12	49.22 b	9.59 ab	2.52 d	12.41 d	161
Ancho	46.90 b	9.76 ab	3.10 a bcd	12.41 d	160
Cacahuacintle	57.53 a	8.95 b	2.77 bcd	12.10 e	165

[†]MCN: moisture content in nixtamal, ^{**}PCN: protein content on nixtamal on dry basis. Means with the same letter in the columns are not statistically different (Tukey, $P \leq 0.05$).

the nixtamalized grain. The differences found in grain texture between genotypes evaluated were mainly due to grain shape, surface area and thickness, which are the traits that affect texture tests (Blandino *et al.*, 2010).

The values of nixtamal hardness (94 kPa EOM vs. 114 kPa Ancho) revealed moderate differences between genotypes, with several EOM materials exhibiting lower resistance to puncture than Ancho maize. This response likely reflects differences in endosperm structure and starch-protein matrix organization rather than just kernel size (Palacios-Pola *et al.*, 2022). The softer texture of nixtamal has been associated with enhanced water diffusion and more efficient starch gelatinization during alkaline cooking (52 % vs. 49 % EOM), which ultimately influences the subsequent popping behavior.

Evaluation in pozole

The cooking time of nixtamal to reach popping (pozole) requires precision and effort because this variable determines the volume, texture, and quality of the popped grain. This value is important in industry because it implies

saving fuel. Popping time was determined in each genotype and each environment by counting the number of popped grains at three cooking times (40, 60 or 80 min).

A linear regression equation was employed for each genotype from the data obtained from each cooking time, to determine the exact moment when 60 % of the grains exploded. Table 5 shows the values of the intercept (m), the slope or regression coefficient (b), the determination coefficient (R^2), and time (T) when grains of each genotype popped. There were significant differences between environments and genotypes ($P \leq 0.05$). For the grains harvested at environment 1 (E1), an average of 49.10 min was required, while 47.97 min were required for the grains harvested at environment 2 (E2). This situation represents an advantage for the Ancho and Cacahuacintle genotypes, which showed a longer popping time with 107.30 and 69.80 min, respectively, for E1, and 104.66 and 68.90 min for E2, since the longer the cooking time, the higher energy consumption (Roque-Maciél *et al.*, 2016). The genotype that required the shortest cooking time was EOM-5 with 24.21 min, followed by EOM-6 with 35.71 min from environment E2, whereas EOM-7 from environment E1 required 32 min.

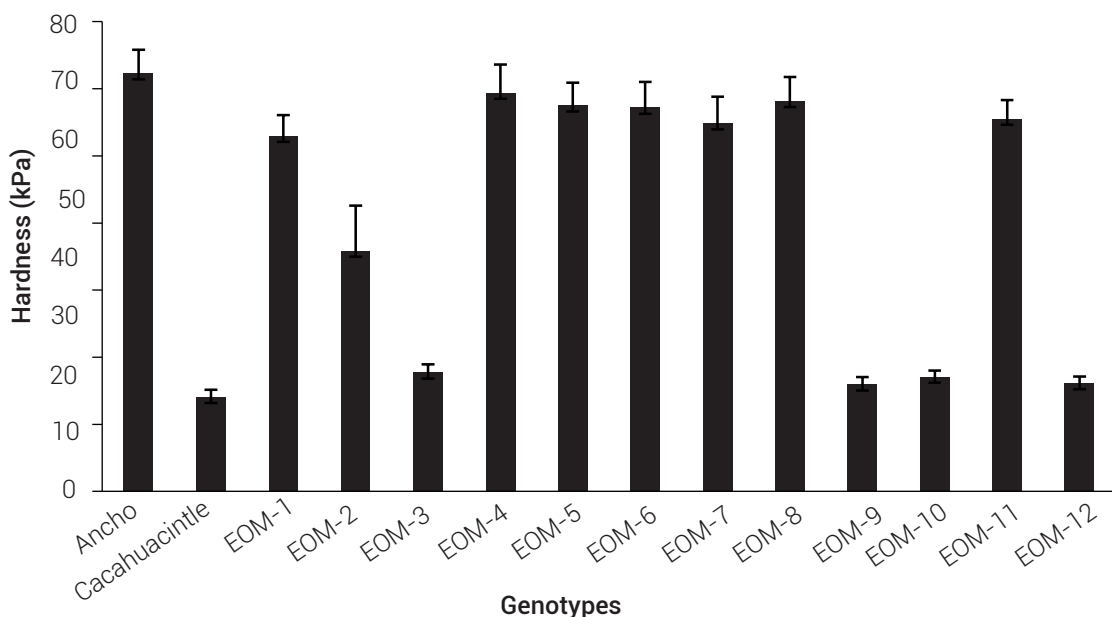


Figure 1. Texture characteristics of nixtamal evaluated as hardness of maize genotypes grains. Bars indicate standard deviation.

Table 5. Parameters of linear regressions of number of popped grains versus popping time for pozole in 14 maize genotypes cultivated in two environments.

Genotype	Environment 1 (E1)				Environment 2 (E2)			
	b_0	m	R ²	T	b_0	m	R ²	T
EOM-1	0.63	17.20	0.99	54.78	0.29	32.77	0.89	50.27
EOM-2	0.55	20.00	0.92	53.23	0.95	-16.32	0.99	40.53
EOM-3	0.65	17.49	1.00	56.40	0.65	12.62	0.94	51.39
EOM-4	0.71	16.92	0.94	59.22	0.66	14.86	0.99	54.50
EOM-5	0.92	-10.72	0.99	44.23	1.24	-50.12	0.88	24.21
EOM-6	0.80	0.00	1.00	48.00	0.86	-15.71	0.75	35.71
EOM-7	1.20	-40.00	1.00	32.00	0.75	9.23	1.00	54.17
EOM-8	1.01	-19.85	0.97	40.88	0.78	3.13	0.98	50.02
EOM-9	0.75	2.27	0.97	47.45	0.55	20.33	0.91	53.03
EOM-10	0.55	20.00	0.92	53.23	0.68	4.97	0.85	45.68
EOM-11	0.80	0.00	1.00	48.00	0.66	15.01	0.97	54.84
EOM-12	0.51	21.31	0.83	51.81	0.58	26.35	1.00	61.30
Ancho	1.70	5.14	0.99	107.30	2.51	-46.05	0.63	104.65
Cacahuacintle	0.63	32.00	0.97	69.80	0.62	31.88	0.98	68.92

E1: environment 1, E2: environment 2, T: popping time, b_0 : the slope, and m: intercept of linear regression equation, respectively. R²: the determination coefficient.

The most notable technological advantage of EOM genotypes was their significantly reduced popping time. EOM materials reached 60 % of popped grains within 24-49 min, compared to 68-107 min for commercial controls. Shorter popping times indicate reduced energy requirements for starch gelatinization and endosperm expansion, consistent with lower vitreousness and a higher proportion of floury endosperm as observed by Miranda *et al.* (2013) and López-Morales *et al.* (2023). These findings align with recent reports linking endosperm modification to improved popping efficiency and represent a substantial reduction in processing time and energy costs by 50-70 % relative to traditional Cacahuacintle-based pozole production, in accordance to Vega-Álvarez *et al.* (2022).

In the popped grain, the starch content decreases as cooking time increases, so the consistency and quality of the popped grain are lost. On the other hand, there was significant differences ($P \leq 0.05$) for volume of pozole between environments, but none for moisture (Table 6). Results indicated a mean volume of 112.42 mL for E1 and 113.67 mL for E2, such values are lower by up to 6 units on average compared to those of local materials. The EOM-5 and EOM-8 genotypes were the smallest with 91 and 98

mL, respectively. It is worth noting that the performance of genotypes in E1 was similar or exceeded those of controls in pozole volume.

For both environments, the genotypes with the highest moisture provided the highest popped grain yields; that is, the higher the moisture content, the higher the volume. The highest volume of expansion occurred in environment 1 (E1). The moisture content and popping time were lower than those reported by Vázquez and Santiago (2013), who reported a 71 % moisture content and a popping time of 149 min for Cacahuacintle maize processed by the traditional method. These results may be due to the physical, chemical and technological properties of the cultivation and processing of the grains, which modify the behavior of Elotes Occidentales maize race, which required less time to explode compared to the controls, or it may be an intrinsic characteristic of Elotes Occidentales because this race exhibits a shorter popping time than other populations of pozole specialty maize.

Regarding the texture as a hardness indicator of pozole, Figure 2 shows that Cacahuacintle maize presented a significantly ($P \leq 0.05$) softer texture of 16.02 kPa,

Table 6. Moisture content and pozole volume of 14 maize genotypes genotypes.

Genotype	Moisture content (%)	Pozole volume (mL)	
		E1	E2
EOM-1	57.22	111	119
EOM-2	57.05	121	114
EOM-3	56.33	110	105
EOM-4	59.07	103	105
EOM-5	57.55	91	102
EOM-6	59.00	123	127
EOM-7	58.57	103	115
EOM-8	58.69	104	98
EOM-9	55.95	127	115
EOM-10	58.65	117	124
EOM-11	57.38	124	120
EOM-12	58.57	115	120
Ancho	60.07	119	116
Cacahuacintle	61.24	120	130

E1: environment 1, E2: environment 2.

compared to the pigmented genotypes averaging a texture of 47.52 kPa. The final texture of pozole confirmed the technological suitability of the selected EOM genotypes. EOM-3, EOM-9, EOM-10 and EOM-12 reached hardness values below 20 kPa, approaching those of Cacahuacintle while maintaining significantly shorter popping times. Although expansion volumes were slightly lower than those of commercial controls (> 90 mL), all selected genotypes exceeded thresholds considered acceptable for commercial production of pozole. Similar results were reported by Miranda *et al.* (2013) and Vázquez and Santiago (2013). It is important to note that nixtamal hardness did not directly translate into the final pozole hardness, which underscores the dominant role of starch gelatinization dynamics during extended boiling rather than initial grain resistance.

Overall, the minimal influence of environment and the consistent performance of EOM genotypes across sites indicate high phenotypic stability under highland conditions. These materials represent a promising alternative germplasm pool for breeding programs targeting fast-processing pozole maize varieties, helping to diversify sources of raw materials and reducing dependence on geographically restricted Cacahuacintle production as previously suggested by Nuss and Tanumihardjo (2010) and Santiago-López *et al.* (2023).

CONCLUSIONS

There are in general considerable variability between Mexican genotypes specialized for preparation of pozole. In addition, there were no changes in the content of grain protein to nixtamal. In regard to moisture content of nixtamal to pozole as the main performance and texture values of pozole, the genotypes of the Elotes Occidentales race had moisture content up to 10 units lower compared to controls. About popping time, the genotypes of Elotes Occidentales presented lower times compared to other varieties, with optimal popping times of up to 25 min; nevertheless, the genotype and the environment influence this trait, which is an important advantage translated into energy savings. Regarding the texture in the pozole process, a group of Elotes Occidentales genotypes showed excellent results with values of around 20 kPa, which implies a shorter popping time and a higher volume of pozole expansion. The EOM-9 genotype offers the best features for the pozole industry, with a popping time of 35-48 min, expansion volume of 115-127 mL and 18 kPa texture in pozole. There are genotypes with stable performance across environments, validating the hypothesis of viable germplasm alternatives for fast-processing pozole production. The Elotes Occidentales genotypes can expand the genetic base for breeding programs targeting cultivation in the High Valleys of Central Mexico.

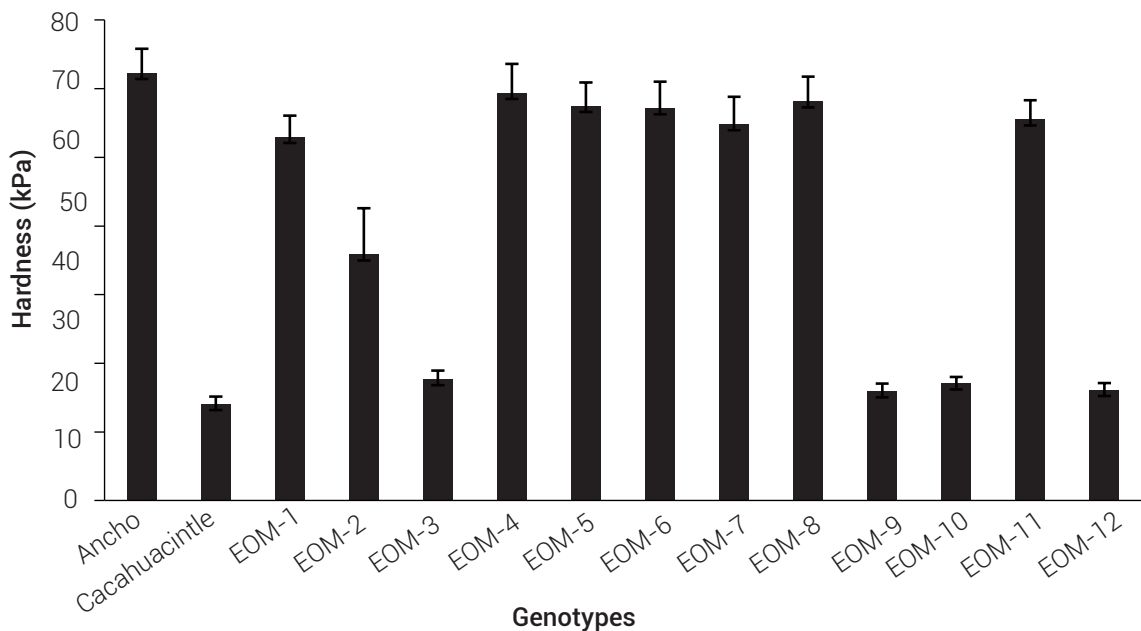


Figure 2. Texture characteristics of pozole from 14 maize genotypes measured as hardness. Bars indicate standard deviation.

BIBLIOGRAPHY

- AACC International, American Association of Cereal Chemists (2010) Approved Methods of Analysis. 11th edition. American Association of Cereal Chemists. St. Paul, Minnesota, USA.
- Agama-Acevedo E., Y. Salinas-Moreno, G. Pacheco-Vargas y L. A. Bello-Pérez (2011) Características físicas y químicas de dos razas de maíz azul: morfología del almidón. *Revista Mexicana de Ciencias Agrícolas* 2:317-329.
- Arellano V. J. L., J. Virgen V. y M. A. Ávila P. (2010) H-66 híbrido de maíz para los Valles Altos de los estados de México y Tlaxcala. *Revista Mexicana de Ciencias Agrícolas* 1:257-262.
- Ballesteros M. G., P. Zarazúa V., Y. Salinas M. y L. de la Cruz L. (2019) Fixation of color in grain and physical, technological and nutraceutical characteristics in corn Elotes Occidentales. *Revista Mexicana de Ciencias Agrícolas* 10:585-599, <https://doi.org/10.29312/remexca.v10i3.1514>
- Blandino M., M. C. Mancini, A. Peila, L. Rolle, F. Vanara and A. Reyneri (2010) Determination of maize kernel hardness: comparison of different laboratory tests to predict dry-milling performance. *Journal of the Science of Food and Agriculture* 90:1870-1878, <https://doi.org/10.1002/jsfa.4027>
- Bonifacio V. E. I., Y. Salinas M., A. Ramos R. y A. Carrillo O. (2005) Calidad pozolera en colectas de maíz Cacahuacintle. *Revista Fitotecnica Mexicana* 28:253-260, <https://doi.org/10.35196/rfm.2005.3.253>
- Campechano C. E. M., J. D. Figueroa C., G. Arámbula V., H. E. Martínez F., S. J. Jiménez S. and J. G. Luna B. (2012) New ecological nixtamalization process for tortilla production and its impact on the chemical properties of whole corn flour and wastewater effluents. *International Journal of Food Science & Technology* 47:564-571, <https://doi.org/10.1111/j.1365-2621.2011.02878.x>
- Figueroa C. J. D., D. E. Narváez G., A. Mauricio S., S. Taba, M. Gaytán M., J. J. Véles M., ... y F. Aragón C. (2013) Propiedades físicas del grano y calidad de los grupos raciales de maíces nativos (criollos) de México. *Revista Fitotecnica Mexicana* 36:305-314, <https://doi.org/10.35196/rfm.2013.3-S3-A.305>
- González J. A. (2018) Corn and food: a brief history of a long journey. *Revista de Geografía Agrícola* 60:09-69, <https://doi.org/10.5154/r.rga.2017.59.007>
- Ibarra-Mendivil M. H., Y. T. Gallardo-Navarro, P. I. Torres and B. Ramírez W. (2008) Effect of processing conditions on instrumental evaluation of nixtamal hardness of corn. *Journal of Texture Studies* 39:252-266, <https://doi.org/10.1111/j.1745-4603.2008.00141.x>
- Jamanca-Gonzales N. C., R. W. Ocrospoma-Dueñas, Y. M. Eguilas-Causi, R. A. Padilla-Fabian and R. J. Silva-Paz (2024) Food grain quality: analysis of physical, biometric, and colorimetric properties to promote consumption. *Heliyon* 10:e29234, <https://doi.org/10.1016/j.heliyon.2024.e29234>
- León-Murillo J. R., R. Gutiérrez-Dorado, R. Reynoso-Camacho, J. Milán-Carrillo, J. X. K. Perales-Sánchez, E. O. Cuevas-Rodríguez y C. Reyes-Moreno (2021) Tortillas elaboradas con harinas extrusionadas de maíz azul y semillas de chíca como opción alimenticia nutritiva y nutracéutica. *Agrociencia* 55:487-506, <https://doi.org/10.47163/agrociencia.v55i6.255>
- López-Morales F., M. G. Vázquez-Carrillo, A. Aragón-García, B. C. Pérez-Torres, M. L. Marrufo-Díaz, G. Hernández-Salinas y A. Ibáñez-Martínez (2023) Caracterización del grano y tortilla de razas de maíz nativas del estado de Puebla, México. *Revista Fitotecnica Mexicana* 46:357-365, <https://doi.org/10.35196/rfm.2023.4.357>
- Mauricio S. R. A., J. D. Figueroa C., S. Taba, M. L. Reyes V., F. Rincón S. and A. Mendoza G. (2004) Characterization of maize accessions by grain and tortilla quality traits. *Revista Fitotecnica Mexicana* 27:213-222, <https://doi.org/10.35196/rfm.2004.3.213>
- Mex-Álvarez R. M. J. (2016) Análisis proximal y fitoquímico de cinco variedades de maíz del Estado de Campeche, México. *Revista Latinoamericana de Recursos Naturales* 12:74-80.
- Miranda A., G. Vázquez-Carrillo, S. García-Lara, F. San Vicente, J. L. Torres, S. Ortiz-Islas and N. Palacios-Rojas (2013) Influence of genotype and environmental adaptation into the maize grain quality traits for nixtamalization. *CyTA - Journal of Food* 11(sup1):54-61, <https://doi.org/10.1080/19476337.2013.763862>
- Muthukumarappan K. and G. J. Swamy (2018) Microstructure and its relationship with quality and storage stability of extruded products. In: Food Microstructure and its Relationship with Quality and Stability. S. Devahastin (ed.). Woodhead Publishing. Cambridge, Massachusetts, USA. pp:161-191, <https://doi.org/10.1016/B978-0-08-100764-8.00009-5>
- NarváezGonzález E. D., J. D. FigueroaCárdenas, S. Taba, E. Castaño T., R. A. Martínez P. and F. Rincón S. (2006) Relationships between the microstructure, physical features, and chemical composition of different maize accessions from Latin America. *Cereal Chemistry* 83:595-604, <https://doi.org/10.1094/CC-83-0595>
- Nuss E. T. and S. A. Tanumihardjo (2010) Maize: a paramount staple crop in the context of global nutrition. *Comprehensive Reviews in Food Science and Food Safety* 99:417-436, <https://doi.org/10.1111/j.1541-4337.2010.00117.x>
- Palacios-Pola P., H. Perales, E. I. J. Estrada L. and J. D. Figueroa C. (2022) Nixtamal techniques for different maize races prepared as tortillas and tostadas by women of Chiapas, Mexico. *Journal of Ethnic Foods* 9:2, <https://doi.org/10.1186/s42779-022-00116-9>
- Paulsmeyer M. N. and J. A. Juvik (2023) Increasing aleurone layer number and pericarp yield for elevated nutrient content in maize. *G3: Genes, Genomes, Genetics* 13:jkad085, <https://doi.org/10.1093/g3journal/jkad085>
- Ramírez-Vega H., G. Vázquez-Carrillo, G. M. Muñoz-Rosales, R. Martínez-Loperena, D. Heredia-Nava, J. A. Martínez-Sifuentes, ... and V. M. Gómez-Rodríguez (2022) Physical and chemical characteristics of native maize from the Jalisco highlands and their influence on the nixtamalization process. *Agriculture* 12:1293, <https://doi.org/10.3390/agriculture12091293>
- Ramírez-Wong B., V. E. Sweat, P. I. Torres and L. W. Rooney (1993) Development of two instrumental methods for corn masa texture evaluation. *Cereal Chemistry* 70:286-290.
- Robles-Ozuna L. E., L. A. Ochoa-Martínez, J. Morales-Castro, J. A. Gallegos-Infante, A. Quintero-Ramos and T. J. Madera-Santana (2016) Effect of nixtamalization conditions ultrasound assisted on some physicochemical, structural and quality characteristics in maize used for pozole. *CyTA - Journal of Food* 14:324-332, <https://doi.org/10.1080/19476337.2015.1110201>
- Roque-Maciél L., G. Arámbula-Villa, M. López-Espíndola, H. Ortiz-Laurel, A. Carballo-Carballo y J. A. Herrera-Corredor (2016) Nixtamalización de cinco variedades de maíz con diferente dureza de grano: impacto en consumo de combustible y cambios fisicoquímicos. *Agrociencia* 50:727-745.
- Ruiz-Gutiérrez M. G., A. Quintero-Ramos, C. O. Meléndez-Pizarro, D. Lardizábal-Gutiérrez, J. Barnard, R. Márquez-Meléndez and R. Talamás-Abbud (2010) Changes in mass transfer, thermal and physicochemical properties during nixtamalization of corn with and without agitation at different temperatures. *Journal of Food Engineering* 98:76-83, <https://doi.org/10.1016/j.jfoodeng.2009.12.010>
- Salinas M. Y., N. O. Gómez M., J. E. Cervantes M., M. Sierra M., A. Palafox C., E. Betanzos M. y B. Coutiño E. (2010) Calidad nixtamalera y tortillera en maíces del trópico húmedo y sub-húmedo de México. *Revista Mexicana de Ciencias Agrícolas* 1:509-523.
- Sanchez G. J. J., M. M. Goodman and C. W. Stuber (2000) Isozymatic and morphological diversity in the races of maize of Mexico. *Economic Botany* 54:43-59, <https://doi.org/10.1007/BF02866599>
- Santiago-López N., J. J. García-Zavala, U. Santiago-López y G. Esquivel-Esquivel (2023) Yield of varieties of pozolero corn of the 'elotes occidentales' race evaluated in High Valleys of Mexico. *Revista Mexicana de Ciencias Agrícolas* 14:100-108, <https://doi.org/10.29312/remexca.v14i5.3225>
- SAS Institute (2009) SAS/STAT User's Guide Release 9.4. SAS Institute. Cary, North Carolina, USA.
- SCFI, Secretaría de Comercio y Fomento Industrial (2002) NMX-FF-034/1-SCFI. Productos alimenticios no industrializados para consumo humano. Cereales. parte I: maíz blanco para proceso alcalino para tortillas de maíz y productos de maíz nixtamalizado. Especificaciones y métodos de prueba. Secretaría de Comercio y Fomento Industrial. México, D. F. https://sitios1.dif.gob.mx/alimentacion/docs/NMX-FF-034-1-SCFI-2002_MAIZ_blanco.pdf (Julio 2025).

- Scott P., R. C. Pratt, N. Hoffman and R. Montgomery (2019) Specialty corns. *In: Corn: Chemistry and Technology*. 3rd edition. S. O. Serna-Saldívar (ed.). AACCI International Press. St. Paul, Minnesota, USA. pp:289-303, <https://doi.org/10.1016/B978-0-12-811971-6.00010-3>
- Vázquez C. M. G. y D. Santiago R. (2013) Características fisicoquímicas y calidad del pozole del maíz Cacahuacintle procesado mediante tres métodos. *Revista Fitotecnia Mexicana* 36:357-366, <https://doi.org/10.35196/rfm.2013.3-S3-A.357>
- Vega-Álvarez E., K. V. Pineda-Hidalgo, N. Y. Salazar-Salas, O. A. Soto-López, V. A. Canizalez-Román, J. A. Garzón-Tiznado, ... and J. A. Lopez-Valenzuela (2022) Genetic and molecular analysis of starch physicochemical properties and its relationship with endosperm modification in quality protein maize. *Biotecnia* 24:140-149, <https://doi.org/10.18633/biotecnia.v24i3.1725>