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Comparing traditional and commercial nixtamalization of three maize landraces: impact on pozole quality and consumer acceptance

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Abstract

One of the most typical dishes of traditional Mexican cuisine is *pozole*, made with nixtamalized maize. This dish has a special place as part of the identity of Mexican culture. However, it is time-consuming to prepare. With an increasing demand for precooked maize for *pozole* and the limited information on its preparation process, this study aims to assess the impact of both traditional (TN) and commercial nixtamalization (CN) on the quality of processed maize and its reception by consumers, focusing on the three most popular maize landraces used in *pozole* recipes. This study was carried out with the Cacahuacintle ('CAC'), Elotes Occidentales ('EO') and Ancho ('AN') landraces, which were nixtamalized using the traditional method (only lime) and the commercial method (lime + additives) and the grain was flowered. The quality of the flowered grain was determined, and a sensory analysis consisting of magnitude of difference tests, a descriptive analysis, affective test and evaluation of consumer preferences was carried out. The 'CAC' landrace, when processed traditionally, yielded the highest sensory and commercial quality. The 'EO' landrace demanded a longer flowering time, resulting in less volume but retaining the aleurone layer. This characteristic helped preserved a portion of the anthocyanins. Consistently, maize landraces subjected to traditional nixtamalization displayed higher ratings for attributes related to masa and nejayote aroma. The 'CAC' landrace subjected to CN faced challenges in acceptability due to odors of acetic acid and sulfuric acid. These findings underscore the importance and advantages the TN techniques. They also emphasize the need to preserve grain quality and meeting consumer preferences when exploring alternative maize processing methods for emerging markets.

Keywords Alkaline cooking, Consumer preference map, Maize landrace, Mexico, Pozole, Sensory evaluation

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Introduction

Economically, maize is the most important cereal on a global scale, with a production of 1137 million tons, surpassing cereals such as rice and wheat. Its use is divided into 56% as animal feed, 15% for non-food proposes and 13% for human food [1]. The industrialization of corn is mainly for the production of starch, from which a wide range of products, such as high fructose syrup, ethanol, polyols, amino acids and gums, are derived. Therefore, its application can range from the food industry in jams, jellies, dressings, processed meats, fruit canning, beverages, bakery products, among many others, to applications such as intermediates for adhesives, biodegradable plastics, cement additives or pharmaceuticals [2].

Maize is a crucial part of the Mesoamerican diet and part of the identity of Mexican culture. This a cereal was developed by the ancient Mesoamericans and it is the plant that is most dependent on man, as its morphology is very different from that of any other cereal. The seeds are covered by several layers of modified leaves that prevent them from spreading and germinating. It has been mentioned that if a maize field is not harvested, in less than 5 years there will be no maize plants left in that field [3].

The diversity with which maize has evolved has allowed it to be consumed in different forms depending on the geographical area. For example, in Mexico is mainly consumed in the form of various nixtamalized maize derivatives [4], whereas in other places, such as Venezuela, Colombia and Panamá, *arepas* made from maize flour are consumed without nixtamalization [5]. In Peru, it is consumed as *choclo* (fresh maize), *cancha* (toasted maize) and *mote* (boiled maize) [6]. In Africa, maize is eaten as a very thick porridge [7]. In Italy, it is eaten as *polenta*, a type of bread [8].

In Mexico, 64 maize landraces have been documented, out of which 59 are considered native [9]. Native maize has remained in Mexico thanks to its adaptation to edaphoclimatic conditions [3]. Despite having lower yields than improved hybrids [10], native maize remains important to producers because only native maize can be used to make certain dishes and is therefore considered a specialty maize [11]. For example, the Bolita landrace is used to make *tlayudas* and *tejate* [12, 13], the Pepitilla landrace is renowned for making the best quality tortillas [11], and the Zapalote chico landrace is used to make *tostadas* and *totopos* [14], to name only a few.

One of the most typical dishes of traditional Mexican cuisine, made with a special type of maize, is *pozole*, a soup made with maize flowered maize grains in a broth, along with meat, radish, lettuce, oregano, chili, onion and lemon [15]. This dish has been prepared since pre-Hispanic times [16]. The origin of the dish is ceremonial, intended for religious celebrations dedicated to the cult of the sun, and could only be eaten by the emperor and high priests [17]. Fray Bernardino Sahagún described in his book '*Historia general de las cosas de la Nueva España"* that the main ingredients of this dish were maize and meat, but with human flesh from warriors captured in battle [17], who were sacrificed in honor of the sun to give them the strength to be reborn the next day [16]. Subsequently, the Spanish colonizers replaced human meat with pork, some of its variations being the use of chicken, fish or seafood, but never beef [15]. *Pozole*, one of Mexico's most representative dishes, is mainly consumed during the celebration of national holidays; however, it has spread throughout specialized restaurants, making its consumption more common [15]. There are three variations of the dish, depending on the geographical region: green *pozole* is mostly eaten in the state of Guerrero; red *pozole* in the western area of the country; and white *pozole* is consumed in the center of the country [18].

The main ingredient of this soup is maize and the landraces vary by region. Approximately 20 maize races, known for their large cobs and grain sizes, as well as soft endosperm, have been identified for this purpose; these include: Ancho, Blando de Sonora, Bofo, Bolita, Cacahuacintle, Chalqueño, Conico, Conico Norteño, Dulcillo del Noroeste, Elotes Conicos, Elotes Occidentales, Gordo, Harinoso de Ocho, Jala, Mushito, Mushito de Michoacán, Tabloncillo, Tabloncillo Perla, Tuxpeño and Vandeño [19, 20]. However, it is well documented that the Cacahuacintle and Ancho landraces are the ones that produce the best quality *pozole*, which is why they are most commonly used for this purpose in the center of the country. On the other hand, in western Mexico, the landrace most commonly used for *pozole* is Elotes Occidentales, which is characterized by the peculiar color of its grains, ranging from lilac, pink, red, purple or blue [21].

Like many dishes derived from maize in Mexico and Central America, the preparation of *pozole* requires nixtamalization or alkaline cooking [22], a process that involves cooking maize grains with calcium hydroxide ($Ca(OH)_2$), and water, with the duration of the cooking process depending on the hardness of the grains used [23]. Two methods have been documented for the preparation of *pozole*: traditional nixtamalization (TN) and commercial nixtamalization (CN).

In the TN method, housewives carry out a laborious process, from selecting the grain to obtaining the final product, which takes about 25 h. On the other hand, in the CN method, small or medium-sized industries, using machinery and chemical products, prepare a precooked grain that can be sold in shops and only requires an additional process of 3 to 4 h to obtain the final dish [20].

The traditional processing (TN) of the flowered grain for *pozole* involves three stages: nixtamalization, deheading and flowering [24].

Nixtamalization involves of cooking the maize in a solution of water and calcium hydroxide ($Ca(OH)_2$) at a concentration that varies from 0.5 to 2.0% of the quantity of maize, depending on the tradition of each housewife. The nixtamal is then left to rest between 8 and 16 h and, at the end of the resting period, it is vigorously washed to remove excess lime and pericarp. The pedicel is then removed by hand in this stage is known as deheading [20]. The aim is to improve the palatability by eliminating the fibrous part of the pedicel, achieving a greater flowering volume and reducing the cooking time of the flowered grain [25]. The deheaded maize is subjected to a final boil, which forms the broth of the *pozole*; this process can take several hours. While cooking, the maize gradually swells and breaks, taking on the shape of a flower, which is why this process is also known as flowering. When the grains are half cooked, the meat is added so that both ingredients (meat and flowered grains) are optimally cooked at the same time. Another variation is that the flowered grains are cooked separately from the meat and, at the moment of serving, they are mixed, incorporating the broth in which the meat has been cooked, so that the dish acquires a characteristic flavor [20].

The commercial method (CN) is used by small or medium-sized companies producing precooked maize; the process used varies greatly from company to company, but the main phases are nixtamalization, deheading and blanching. Unlike the TN process, the CN process is carried out with lower concentrations of calcium hydroxide, ranging from 0.3 to 0.5%; however, in this process sodium hydroxide is added in varying amounts depending on the experience of the company. The purpose of this is to facilitate the separation of the pericarp and the pedicel. The cooking of the nixtamal takes about one hour. Once this time has elapsed, the maize is deheaded using a device consisting of a tank equipped with a transverse axis with paddles that rotate to rub the nixtamal against the walls of the tank, so that the pedicel and pericarp are detached from the nixtamal with the help of a continuous flow of water [26]. Deheading is a practice used to reduce flowering time [25], as it enables the entry of water into the grain, favoring the gelatinization of starches in the endosperm [20].

In some companies, after the heading stage, a process called precooking is carried out, which consists of cooking the maize with phosphoric acid for a short time [26]. In central Mexico, consumers prefer very white maize grains. This custom is part of the cultural heritage, since the ancient Mexicas used the Cacahuacintle landrace maize, which is a white grain, associating the white color with divinity and with their worldview of the world [16]. Due to this, the agroindustry produces a product with these characteristics, so once the grain is deheaded, it is bleached, using sodium metabisulfite in concentrations that can vary from 3 to 7.5% and acetic acid (2%) [26], or hydrogen peroxide (Burgos, 2023; pers. comm.). The maize is left to stand in the bleaching solution for 20 h and, finally the water is drained and the grain is packed.

Sodium hydroxide is an acidity regulating additive; however, in the production of precooked bleached grain, it is used to help remove of the pedicel during heading. Sodium metabisulfite is used as a bleaching agent in the bleaching process. The purpose of the acetic acid is to lower the pH of the grain so that the preservatives can work; it also aids in bleaching and, according to processors, softens and fluffs the grain so that it appears larger [27]. Phosphoric acid also has the function of sponging the grain. Sodium benzoate serves as a preservative in packaging, although some companies do not require this additive because they package the bleached grain precooked in a vacuum. These additives are used indiscriminately by the industry, since there is currently almost no research on the specific effects of these compounds on the manufacturing process or on the optimal amounts to be used without affecting the functional and sensory quality of the final product and the nutritional value for the end consumer. It is worth mentioning that, to date, the industrial process is not regulated by standards and the processing of precooked bleached cereals is the responsibility of each company [28].

It is important to note that health authorities do not currently oversee the commercial nixtamalization (CN) process. This results in a substantial elevation of sodium levels in the processed grain, which can be contraindicated for individuals with hypertension [20, 29].

The Cacahuacintle landrace is recognized as the best one for *pozole*, given the quality and yield of the dish [30], and over the years it has been the most studied in terms of its technological characterization during nixtamalization [25, 26, 31, 32]. However, very recently more research has been done using other landraces, such as Ancho, Bofo Harinoso de ocho, Bolita, Chalqueño, Cónico, Jala, Tabloncillo, Tuxpeño [24] and Elotes Occidentales [21, 33]. Nevertheless, little is known about its sensory acceptance and consumer preferences. Thus, the objective of this research was to evaluate the physical characteristics of maize grains of the main landraces for *pozole* production, the effect of traditional and commercial nixtamalization on the quality of the flowered grain and consumer preference when using the Cacahuacintle, Ancho and Elotes Occidentales maize landraces.

Methods

Genetic material

Maize landraces including Cacahuacintle ('CAC'), Ancho ('AN') and Elotes Occidentales ('EO') were evaluated. They were purchased in local markets in Ciudad Serdán, Puebla; Cuautla, Morelos and Guadalajara, Jalisco, in Mexico, respectively. 'AN' and 'CAC' grains are white, while 'EO' is purple. Before utilization, impurities and incomplete grains were removed, and moisture was standardized to a range of 12 and 13%.

Physical analysis of maize grains

The test weight was evaluated following the AACC International method 55.10.01 [34]. The weight of one hundred grain was measured using the method described by Vázquez-Carrillo et al. [24]. The flotation index (FI) was determined following the standard Mexican methodologies for maize: NMX-034/1 [35]. The latter two variables are used as indirect measures of grain size and hardness, respectively. The percentage of pericarp was quantified using NMX-034/1 [35], while the thickness of pericarp was determined following the method described by Wolf et al. [36].

The color of the raw grain, nixtamal, bleached and flowered grain were measured with a HunterLab Mini Scan XE Plus colorimeter (Model 45/0-L Series 5348), using the CIE Lab scale, illuminant C and an observer angle of 10°. The values of L*, a and b were obtained, and the hue and saturation index (SI) were calculated [37]

Nixtamalization and flowered grain quality

Traditional nixtamalization (TN)

Four hundred milliliters of water was heated with 1.4 g of $Ca(OH)_2$ (0.7% based on maize). When the water started boiling, 200 g of maize was added. The nixtamalization time was assigned according to the flotation index [35]. Thus, the three maize landraces were cooked for 25 min. After cooking, the samples were left to soak for 14 h at room temperature (22 °C). The cooked grains (nixtamal) were washed, and the pedicel was removed by hand. The grains were boiled in water until 50% of them opened in a flower-like shape (flowered grains) [24]. The steps to follow are shown in Fig. 1.

Commercial nixtamalization (CN)

This was carried out with the same amounts of maize, water and $Ca(OH)_2$ as the TN. In addition, 8 mL of 50% NaOH (food grade) were added and the grains were cooked for 50 min. After cooking, the nixtamal was left to soak for 60 min at room temperature (22 °C). Immediately afterward, the nixtamal was washed and the pedicel was removed by rubbing the grains against the walls of a plastic basket. The nixtamal was bleached with 300 mL of water at 70 °C, with $Na_2S_2O_5$ (6 g 100 g^{-1} of maize). When the temperature dropped below 50 °C, 4 mL of acetic acid (food grade) were added. After 20 h of blanching, the nixtamal was washed and boiled until 50% of the grain was observed to flower (Fig. 1) [24].

Flowered grain quality

Dry matter loss (DML) in the maize cooking liquor (nejayote), bleaching solution, wash water and final cooking liquor was quantified following the method by Vázquez-Carrillo & Santiago Ramos [26]. The time required to obtain flowered grain was recorded from the start of boiling until 50% of the grain assumed a flower-like shape [25]. Flowered grain volume (FV) is expressed in cm^3 per 100 g of raw grain. The moisture of the flowered grain was quantified with method 44–10 by AACC International [34]. Puncturing force (PF) was determined with a Brookfield texturometer (model CT3, Middleboro, MA, USA) as described by Vázquez-Carrillo et al. [24].

Sensory analysis

The flowered grains of the 'CAC,' 'AN' and 'EO' landraces were processed using the traditional nixtamalization method. Additionally, a sample (Commercial CAC) processed using the commercial nixtamalization method was included for comparison. All the panelists were informed about the purpose of the study and gave their consent before the tests began.

Magnitude of difference

The sensory distinctions between pairs of flowered grains ('AN' vs. 'EO'; 'AN' vs. 'CAC'; 'EO' vs. 'CAC'; and 'CAC' vs. 'Commercial CAC') were assessed using 90 triangular tests, each conducted with two repeated measurements. The panelists were individuals who consumed *pozole* at least three times a year. Due to the noticeable differences in the appearance of the maize landraces, the judges' vision was obscured with sleeping masks, and 10 assistants aided each judge in following the methodology and during the tasting sessions [38].

For each landrace, three flowered grains were presented to the panelists. Additionally, glasses of water were provided to the panelists as palate cleansers between tastings.

Descriptive analysis

In order to select panel judges, a sequential analysis was performed [38]. The judges claimed that they ate *pozole* at least three times a year. The panel was composed of 14 trained judges (four men and ten women), ranging from 22 to 24 years of age. All judges had prior experience in descriptive techniques. The training program

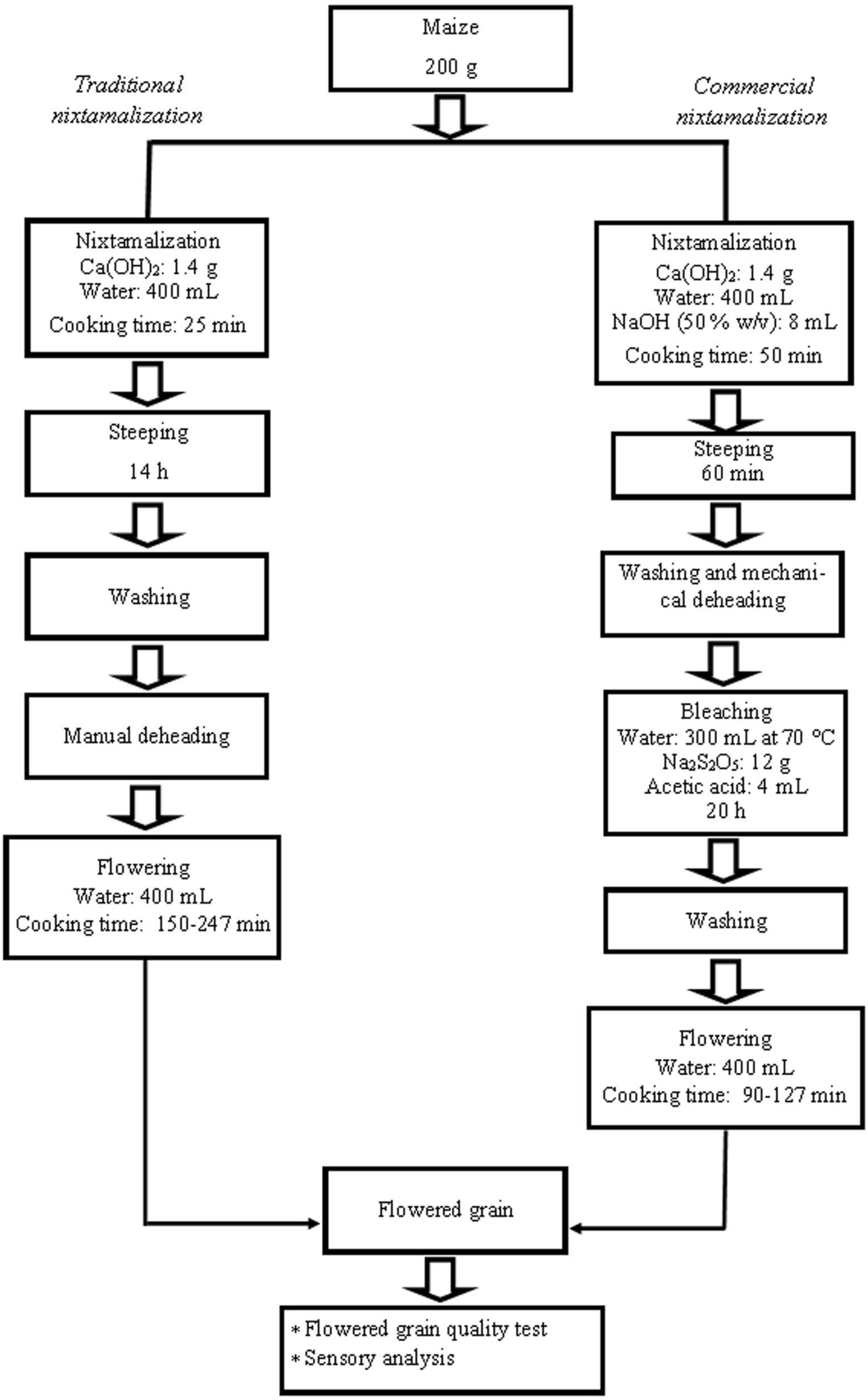

Fig. 1 Flow diagram for obtaining flowered grain by two methods

was conducted following with the guidelines outlined in AENOR [39]. Panelists underwent a comprehensive 20-h training program to acquaint themselves with the method, scale, attributes and references used, as per the guidance provided by Lawless & Heymann [40].

The panelists provided specific descriptions for the various flowered grains (Cacahuacintle, Ancho, Elotes Occidentales and Commercial Cacahuacintle) and developed their own terminology. Consensus was reached on the grain descriptors. Panelists proposed references and collectively agreed on their intensity using 15 cm interval scales (ranging from 0 = not present to 15 = extremely strong). Nineteen descriptors were considered, encompassing six for appearance, four for aroma, five for texture and four for flavor (Table 1). Samples comprising six flowered grains were presented at a controlled room temperature of 20 °C ± 2 °C. The evaluation took place in individual cabins within a specialized sensory evaluation laboratory. Panelists were provided with crackers, water glasses and references throughout the session, and each sample was assessed in triplicate.

Table 1 Sensory descriptors, definition and references of flowered grains produced with the Ancho, Cacahuacintle and Elotes Occidentales maize landraces

Attributes/descriptors		Definition	References
Appearance	Lightness	Light beam reflected from the surface and observed at 45°	Natural yogurt Alpura®, Farmers Producers of Pure Milk A.C. (Intensity = 11)
	Yellow tone	580 nm wavelength reflected and observed at 90°	Salt-free margarine Iberia® Unilever de México S.A. de C.V., (Intensity = 12.5)
	Purple tone	620 nm wavelength reflected and observed at 90°	Blackberry yogurt Alpura®, Farmers Producers of Pure Milk A.C. (Intensity = 7)
	Size	Dimension of length expressed in three-dimensional form	Chili chickpeas (Intensity = 4) and chili bean (Intensity = 13) Great Value®, Wal-Mart de México, S. de R.L. de C.V
	Flowered grain	Shape that the endocarp takes after cooking (when it expands)	Popmaize Del carrito® (Intensity = 13.5)
	Dent appearance	Grain shape resembling incisor tooth	Chili bean Great Value®, Wal-Mart de México, S. de R.L. de C.V. (Intensity = 12)
Aroma or odor	Dough (masa) aroma	Aroma related to the nixtamalized and ground maize grain	Nixtamalized and ground maize (Intensity = 10)
	Nejayote aroma	Aroma related to that of the residual broth of a solution of lime and maize grain, after heating	Residual broth from a solution of lime and nixtamalized maize grain (Intensity = 13)
	Acetic acid odor	Acetic acid odor	5% acetic acid solution (Intensity = 12)
	Sulfuric odor	Sodium bisulfite odor	10% sodium bisulfite solution (Intensity = 10)
Texture	Rugose	Sensation on the tongue of the irregularity of the surface of the grain	Tortillina (wheat flour tortillas) Tía Rosa® Grupo Bimbo S.A.B. de C.V. (Intensity = 2) and tostadas (toast tortillas) charras® (Intensity = 12)
	Hardness	Force to penetrate the maize grain with the molars	Pitted green olives Carbonell® Comercial México, S.A. de C.V. (Intensity = 3) and chili chickpeas Great Value® Wal-Mart de México, S. de R.L. de C.V. (Intensity = 11.5)
	Moisture	Perception of the water released by the grain after chewing	Peeled and seedless cucumber (Intensity = 9)
	Cohesiveness	Ability of a sample to deform without tearing	Medium marshmallow de la Rosa® (Intensity = 5) and flavored soft candy Sugus® (Intensity = 14)
	Granularity	Particle residues perceived during chewing	Roasted and seasoned premium peanuts Mafer®, Sabritas, S.de RL de CV., (Intensity = 2.5) and chili chickpeas Great value® Wal-Mart de México, S. de R.L. de C.V. (Intensity = 12.5)
Flavor	Acid	Basic flavor perceived when tasting an acid solution	0.05% acetic acid solution (Intensity = 7)
	Sweetness	Basic flavor perceived when tasting a sucrose solution	2% sucrose solution (Intensity = 9)
	Dough flavor	Permanent sensation after ingesting the grain, which evokes the nixtamalized and ground maize grain	Nixtamalized and ground maize (Intensity = 10)
	lime flavor	Sensation that remains when ingesting calcium hydroxide in the oral cavity	0.5% calcium hydroxide solution (Intensity = 8)

Affective tests
This test was conducted with an untrained panel, consisting of 100 people selected as regular consumers of *pozole*. The panel size was determined according to Meilgaard et al. [38], who mention that the panel size can range from 75 to 300 consumers to obtain statistically reliable data. The acceptability of specific attributes (shape, color, aroma, taste, flavor, hardness and residual flavor) and overall acceptability were evaluated for each sample (Cacahuacintle, Ancho, Elotes Occidentales and Commercial Cacahuacintle). Both tests were carried out at different times and in different formats with a group ($n = 100$) of *pozole* consumers (students and administrative staff of the Universidad Autónoma Chapingo), 46 men and 54 women, aged 18 to 55 years. The samples were presented randomly and monadically in coded plastic cups. A nine-point hedonic scale (1 = extremely disliked and 9 = extremely liked) was used for the evaluation [38].

Evaluation of consumer preferences for maize landraces, processing methods and commercial presentation of maize grain for pozole
The panelists, consistent with those participating in the affective tests, were presented with flowered maize grains from the Cacahuacintle, Ancho and Elotes Occidentales landraces in a randomized fashion. They were then asked a series of eleven questions, divided into four sections: (1) Their initial choice or preference for each of the flowered grains. (2) Their final choice or preference for the same set of grains. (3) Their preferred method of preparation of the *pozole* grains (nixtamalized at home or through industrialized means). (4) Their preference for the type of presentation for the industrially processed grains (canned, packaged in plastic bags or neither).

Responses were recorded as binary data, with '1' indicating a selection and '0' indicating no selection.

Statistical analyses
Flowered grain quality
A completely randomized design with a factorial arrangement was used to evaluate the effects of the nixtamalization method (TN and CN), maize landrace (G) and NxG interaction on the response variables of flowered grain quality. Tukey's test ($P \leq 0.05$) was used for statistically significant variables. The results were analyzed using the SAS statistical package, version 9.4 (SAS Institute, Inc., Cary, NC).

Magnitude of difference
Triangular tests with two repeated measures were used to analyze the data with the corrected beta-binomial model and to calculate the magnitude of difference (d' value) of the sample pairs and the power of the triangular tests [41], using Tools version 2019 software.

Descriptive analysis
The parameters of the sequential analysis were $\alpha = 0.05$, $\beta = 0.1$, po = 0.33 and pd = 0.5. A judge with five consecutive correct judgments was accepted, a person with four consecutive incorrect judgments was rejected, the maximum unacceptable ability of an individual was nine judgments, and the minimum acceptable ability was 11 [38]. A principal components analysis was used to monitor panelists during training [40]. For the quantitative descriptive analysis, a randomized complete block design with a split-plot arrangement was used. The sample effect is referred to as the larger plot effect, whereas the judges and the judge-by-sample interaction are the split-plot effects. The significance of the panel replicates, the judges and the judge-by-sample interaction were calculated with their respective error terms. When an interaction was found to be significant, a plot of the judges-by-sample means for a particular descriptor was examined to identify the judges causing the interaction for further training [38]. If analyses of variance for each of the response variables did not show a significant difference ($p > 0.05$) for panel replicates and the judge-by-sample interaction but did show a difference for samples ($p \leq 0.05$), the least significant difference procedure was used.

Affective tests
The experimental design used for the affective tests was a complete randomized block design, where the blocks were the panelists, and the flowered grains of the maize landraces were randomly assigned to each of them. With the dissimilarity matrix, agglomerative hierarchical clustering (AHC) was applied, using Euclidean distances and Ward's method to obtain a dendrogram showing the progressive clustering of the acceptability data, with the Hartigan index. With the acceptability data centered (the mean of each judge is set to zero), an analysis of variance under a completely randomized design and other analyses were performed for each of the groups formed with the AHC. Internal preference maps were obtained using principal component analysis.

Evaluation of consumer preferences for maize landraces, processing methods and commercial presentation of maize grain for pozole
The external preference map was created using a partial least squares regression (PLSR). The 11 background variables were binary in nature, yes/no (1/0), and were transformed into 11 new variables Y (Z), each with four rows representing the maize types, to make them compatible with the sensory descriptors of the maize (Y1). The

flowered grain descriptors were simultaneously linked to consumer background variables within a graphical interpretation of consumer product preference patterns. To facilitate data analysis, this linkage is performed within the same two-block bilinear modeling framework as the preference mapping. The Unscrambler version X 10.2 (Camo Process AS, Oslo, Norway) was used. The PLSR was performed with the acceptability and ($Y = [\text{Y1, Z}]$) of four types of flowered grains evaluated by 100 consumers [42], using the maize descriptors (Y1) and the consumer background variables (Z) represented by the consumer data on maize selection, nixtamalization method and type of presentation of the commercial grain.

Results and Discussion

Physical characteristics of maize grain

The analysis of variance for grain physical characteristics displayed a significant difference ($p \leq 0.05$) between the three samples. All three maize landraces were classified by FI as having soft endosperm grains (> 95% floating), low test weight (< 72 kg hL^{-1}) and large grains (67.1 g/100 grains). The landrace with the highest proportion of pedicel was 'CAC' (2.42%).

Flowered grain quality

The results presented significant differences ($p \leq 0.05$) between nixtamalization (N) methods (TN and CN), between genotypes (G) and the NxG interaction. Aside from moisture and the saturation index of flowered grains, the significance of the NxG interaction for the remaining variables indicated that the genotypes had different responses to the nixtamalization methods.

The commercial nixtamalization (CN) process led to a notable reduction in flowering time by 47%. However, it resulted in a higher dry matter loss (11%) due to the use of $Ca(OH)_2$ and NaOH, as well as the extended bleaching period (20 h). Similarly, flowered grains processed with CN displayed higher moisture content (67.3%) and attained greater volume and softness compared to those treated with traditional nixtamalization (TN) (Table 2). Furthermore, the flowered grain yield for CN was lower than that of TN, recording 2.4 kg and 2.5 kg of flowered grain per kilogram of raw maize, respectively. These findings coincide with previous studies conducted by Vázquez-Carrillo et al. [24] on nine commonly used landraces for *pozole*.

The comparison between landraces revealed that 'CAC' presented the highest moisture content and flowered grain yield at 66.2% and 2.5 kg of flowered grain per kilogram of raw maize, respectively. This can be attributed to the larger size of its starch granules, as indicated by Bonifacio Vázquez et al. [25]. Additionally, research by Figueroa et al. [30] highlighted that 'CAC' possesses the lowest gelatinization temperature and the highest pastification temperature after cooking, in comparison with other landraces. Moreover, it has a greater proportion of floury endosperm (80%) [24]. Studies have also pointed out that starch granules in 'CAC' have larger intracellular spaces, facilitating easier water diffusion, hence increasing water absorption [43].

Flowered grains of the 'AN' landrace had the softest texture in both nixtamalization treatments and recorded the lowest puncture strength, followed by 'CAC' and 'EO' (Table 2). The purple 'EO' landrace (Fig. 2) had the lowest values for lightness (52.3%), hue (48.1° reddish hue) and SI (15), while 'CAC' had the highest values for L* (78.3 %). hue (89.3°), and SI (18.5). On the other hand, 'AN' had 72.2%, 88.3° and 24.6 respectively. Both 'AN' and 'CAC' grains were cream-colored, a trait highly sought after by consumers for *pozole* production in various regions of Mexico where this maize is cultivated [28, 31].

In the flowered grains obtained through CN, the reduction in lightness (Fig. 2A) could be attributed to the complete gelatinization of their starches following the prolonged cooking time. In the flowered grains of the 'EO' landrace after CN, the hue increased up to 82° toward yellow-orange tones (Fig. 2B). This transformation is a result of the degradation of anthocyanins, the

Table 2 Quality traits of raw grain and flowered grains of Ancho (AN), Cacahuacintle (CAC) and Elotes Occidentales (EO) maize landraces

Landrace	TW kg hL^{-1}	HGW	DML (%)		Flowering time (min)		Flowering volume (cm^3 100 g^{-1})		Puncture force (N)	
			TN	CN	TN	CN	TN	CN	TN	CN
AN	65.2 b	80.5 a	5.8 cB	11.7 aA	247 aA	127 aB	412 aB	440 aA	0.72 bA	0.47 cB
CAC	59.1 c	66.4 b	6.4 aB	10.9 bA	150 cA	125 aB	384 bB	440 aA	0.82 aA	0.54 bB
EO	71.7 a	54.3 c	6.1 bB	10.5 cA	214 bA	90 bB	420 aA	415 bA	0.83 aA	0.55 aB

TW: Test weight; HGW: hundred grain weight; DML dry matter lost

Low-capital letters indicate statistically significant differences in columns. Capital letters indicate statistically significant differences in values from the same row (Tukey, 0.05)

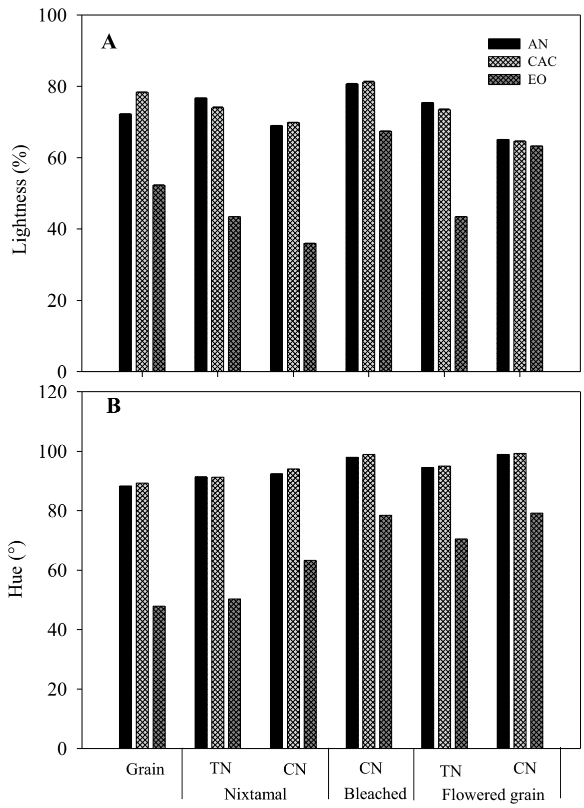

Fig. 2 Effect of the nixtamalization method on lightness (**A**) and hue (**B**) in grain, nixtamal, bleached and flowered grain of Ancho (AN), Cacahuacintle (CAC) and Elotes Occidentales (EO) maize landraces

pigment responsible for the characteristic color of the grain, as well as the loss of the aleurone layer (Fig. 3). Studies have revealed that up to 82% of anthocyanins are lost during nixtamalization [44]. However, in hybrids derived from the Elotes Occidentales landrace, it has been reported that anthocyanin losses from raw grain to flowered grain range from 48 to 68% [33], as traditional nixtamalization retains the aleurone layer (Fig. 3).

As mentioned above, TN produces a similar flowering grain quality to CN, with a lower dry matter loss and without the addition of bleaching agents. The main advantage of CN is that it reduces flowering times and facilitates pedicel removal.

Sensorial analysis of flowered grain

Magnitude of difference between pairs of flowered grains

All pairs of maize landraces assessed in the blind tests were discerned to be different ($p \leq 0.01$), with small overdispersions observed (variability within and between judges) $\gamma < 0.11$. The d' values or magnitudes of difference (Table 3) ranged from 1.41 to 2.33 for the pairs 'EO' vs. 'CAC' and 'CAC' vs. 'Commercial CAC.' The calculated powers ($1-\beta$) for the four tests were high (≥ 0.98). The power of a test means the likelihood of accepting the alternative hypothesis if it is indeed true. These findings declare that the judges discerned sensory disparities in flavor and texture attributes, regardless of any potential differences in appearance.

Descriptive analysis

The comparison of descriptor means shown in Table 4 revealed significant differences ($p \leq 0.05$) between the

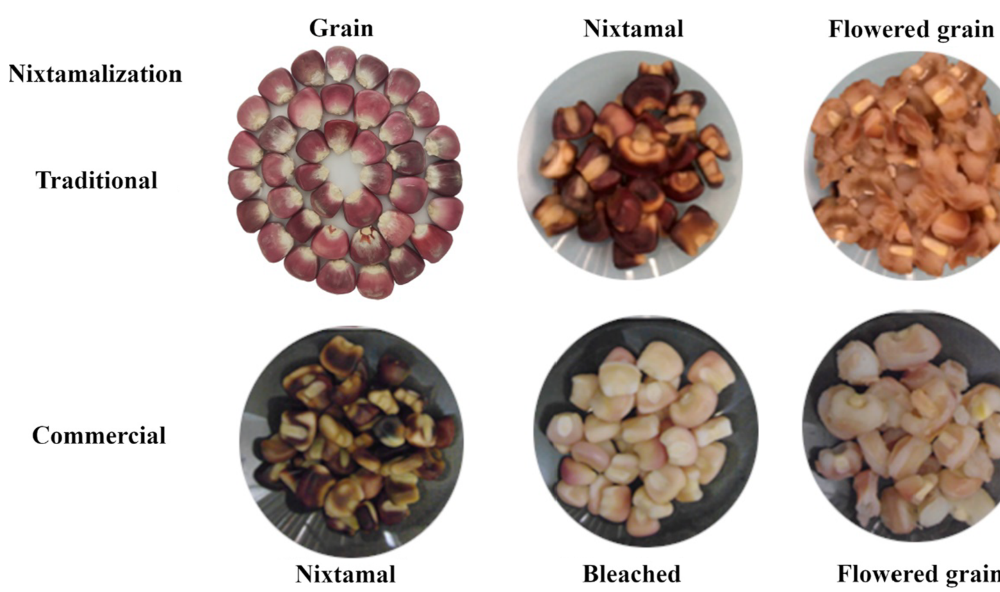

Fig. 3 Nixtamalization method effect on grain color of Elotes Occidentales (EO) maize landrace

Table 3 Magnitudes of difference obtained with triangular tests with repeated measurements ($n=90$; $k=2$), for pairs of flowered grains

Compared pairs	Over dispersion (γ)	d' Value	Significance (Ho: $p=0.33$)	Power of the test ($1-\beta$)
AN vs EO	0.006	1.61	1.0×10^{-7}	0.99
AN vs CAC	0.107	1.97	1.0×10^{-7}	0.99
EO vs CAC	0.010	1.41	1.5×10^{-5}	0.98
CAC vs Commercial CAC	0.006	2.33	4.0×10^{-6}	0.99

AN = Ancho; EO = Elotes Occidentales; CAC = Cacahuacintle; all with traditional nixtamalization method

Commercial CAC = Cacahuacintle with commercial nixtamalization method

n = number of consumers, k = repeated measurements

Table 4 Means comparison of sensory descriptors of flowered grain prepared with Ancho (AN), Cacahuacintle (CAC) and Elotes Occidentales (EO) landrace nixtamalized by the traditional method and Commercial CAC by commercial nixtamalization

	AN	EO	CAC	Commercial CAC
Appearance				
Lightness	0.87 c	0.27 d	1.44 b	9.73 a
Yellow	11.43 a	0.47 c	9.92 b	0.33 c
Purple	0.12 b	7.17 a	0.14 b	0.12 b
Size	10.38 a	6.81 b	7.50 b	7.96 b
Flowered	4.58 c	5.25 c	8.30 a	6.62 b
Dent	9.71 a	6.14 b	4.88 c	4.12 c
Aroma				
Dough	5.35 b	6.08 ab	6.10 a	2.76 c
Nejayote	8.21 a	6.60 b	5.77 b	3.60 c
Acetic acid	0.48 b	0.27 b	0.19 b	3.04 a
Sulfuric acid	0.33 b	0.29 b	0.18 b	1.51 a
Texture				
Rugosity	6.78 a	5.06 b	6.19 a	3.66 c
Hardness	5.44 b	6.27 a	3.22 c	3.83 c
Moisture	4.20 b	3.55 b	5.03 a	5.47 a
Cohesiveness	6.59 b	6.49 b	6.46 b	7.47 a
Granularity	4.48 b	5.98 a	3.59 c	2.65 d
Flavor				
Acid	0.27 b	0.14 b	0.15 b	4.11 a
Sweet	0.96 a	0.94 a	1.14 a	0.36 b
Dough	4.62 a	4.97 a	4.72 a	2.93 b
Lime	0.90 a	0.64 ab	0.67 ab	0.54 b

Letters in the same row indicate statistically significant differences (Tukey, 0.05)

landraces evaluated. 'Commercial CAC ' stood out for its higher lightness, sour taste and sulfuric and acetic odors, which are attributes influenced by specific preparation method involving the use of sodium metabisulfite and acetic acid in the bleaching process. Additionally, this maize sample had higher cohesiveness and lower attributes for the dough aroma, sweetness, dough flavor and lime flavor (Table 4). The differences between landraces 'AN,' 'EO' and 'CAC' were due to shape, size and color, which are inherent features of each landrace's grains. While significant differences were found in aroma and texture attributes, panelists did not perceive substantial distinctions in flavor attributes (Table 4).

Affective test

The acceptability scores of the flowered grains exhibited significant differences ($p\leq0.05$). The 'CAC' landrace processed with TN had the highest acceptability score (6.66a ± 1.40), whereas the 'CAC' landrace processed with CN had the lowest acceptability score (4.52c ± 2.37). The 'AN' and 'EO' landraces had acceptability scores of 5.59b ± 1.99 and 5.43b ± 1.78, respectively, which were statistically similar. Figure 4A displays the internal preference map for the four types of flowered grains. The first component explained 54.85% of the variance, while the second component explained 25.83% (cumulative 80.68%). This graph indicates that panelists on the right side preferred the 'CAC,' 'EO' and 'AN' landraces, whereas those on the left side favored the Commercial 'CAC.' The Hartigan index results led to the formation of two distinct consumer groups with different acceptabilities (Table 5). In the first group ($n=51$), the 'CAC' with TN grain had the highest acceptability, followed by 'AN' and 'EO,' which were statistically equivalent. Conversely, the 'Commercial CAC' processed with CN had the lowest acceptability. In the second group ($n=49$), both 'CAC' with TN and CN had the highest acceptance, being statistically equivalent. They were followed by 'AN' and 'EO.' The internal preference maps (Fig. 4B and 4C) illustrated this acceptance behavior toward the various maize types for both consumer groups. The first two components accounted for 86% and 76.77% of the variability for groups one and two, respectively.

The external preference map for the four types of flowered grains explained 86% of the total variability (Fig. 5A). The highest overall acceptability was associated with 'CAC,' with attributes including sweetness, yellowness, dough aroma, roughness, dough flavor and flowering. On the other hand, the consumer group ($n=100$) had the lowest acceptability for 'Commercial CAC,' which can be attributed to the presence of acetic and sulfuric odors, as well as the higher intensity of acid flavor.

Evaluation of consumer preferences for maize landraces, processing methods and commercial presentation of maize grain for pozole

The results of the partial least squares regression (L-type) for the three data matrices (maize descriptors, consumer

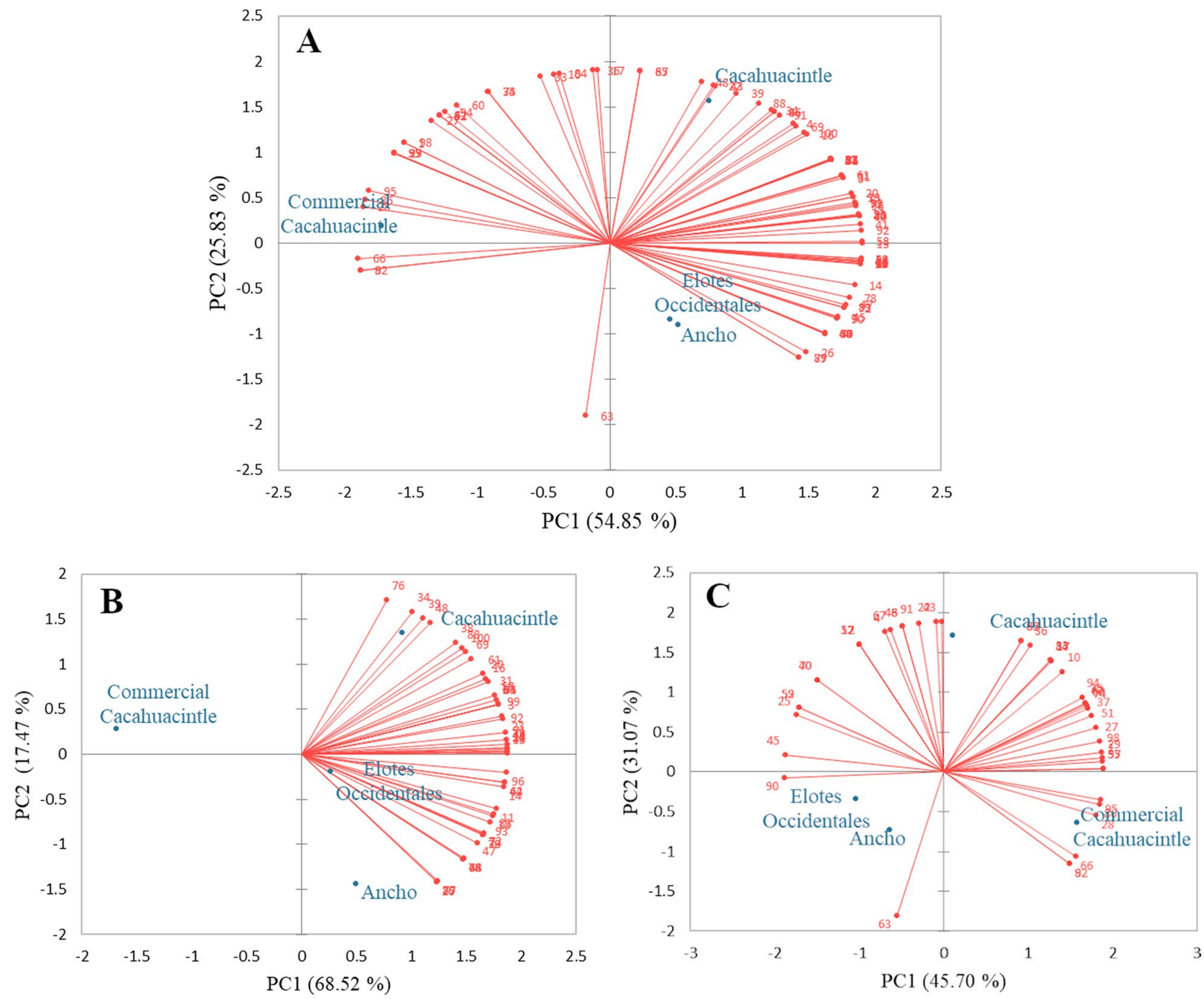

Fig. 4 Internal preference map of flowered grains (**A**), internal preference maps of identified groups of flowered grain consumers (**B**, **C**)

Table 5 Overall acceptability of flowered grains of maize landraces, by consumer group

Landrace	Acceptability after centering the assessors
Group 1 (n = 51)	
Cacahuacintle	1.529 ± 0.174 a
Ancho	0.667 ± 0.174 b
Elotes Occidentales	0.333 ± 0.174 b
Commercial Cacahuacintle	-2.529 ± 0.174 c
Group 2 (n = 49)	
Cacahuacintle	0.684 ± 0.168 a
Ancho	0.520 ± 0.168 a
Elotes Occidentales	-0.602 ± 0.168 b
Commercial Cacahuacintle	-0.602 ± 0.168 b

Different letters in the same column indicate statistically significant differences (Tukey, 0.05)

acceptance and consumer background) are presented in Fig. 5B. This graph displays the ratings of maize types and the correlation loadings of consumers, flowered grain descriptors and consumer background on maize landrace choice, processing method and preference for commercial grain presentation type.

The first two components accounted for 57% and 32% of the variability in the sensory descriptors of the flowered grains, respectively. In terms of acceptability, the first two components explained 4% and 1% of the variability, while the consumer background (habits and attitudes) could be explained with two components accounting for 27% and 35% of the total variability.

Figure 5B shows two groups of consumers, with one on the left and a larger group on the right. This indicates that although there were consumers who accepted the flowered 'CAC' grains with the CN, the majority of

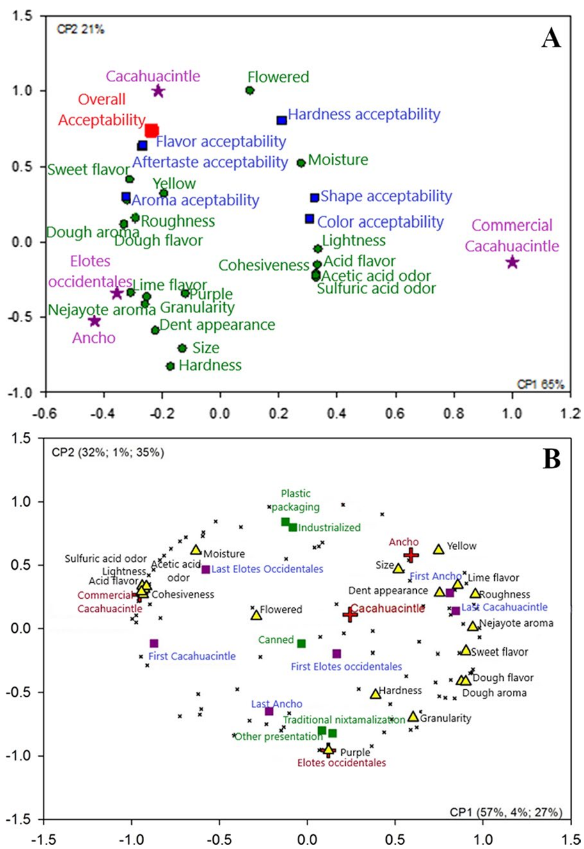

Fig. 5 External preference map of flowered grain of four types of maize for *pozole*. Descriptors (green), overall acceptability (red), acceptability by attributes (blue) and landraces (purple) (**A**). Preference map for the flowered grain of four types of maize for *pozole*. Descriptors (yellow triangles), acceptability (black crosses), first and last preference of maize landraces (purple squares), grain consumption preferences (green squares) and maize landraces (red crosses) (**B**)

consumers preferred the flowered 'CAC' grains with the TN, along with those of 'AN' and 'EO.' Landraces that were most accepted by consumers were characterized by a more intense aroma of dough and nejayote, in addition of its sweetness flavor. Conversely, the flowered 'CAC' grains with CN had the lowest acceptance frequency, along with the highest intensity attributes such as sulfuric and acetic odors, a moist appearance, cohesiveness and lightness. There was consistency in the selection of the first and last choices of landraces 'AN' and 'EO'; their first and last choices were on opposite sides, and the first choice was closely aligned with the location of the landrace. The close position of the first choice of 'CAC' with 'Commercial CAC' can be attributed to the higher perceived lightness in the visual evaluation of 'Commercial CAC,' which, according to Fig. 4B and C, had the highest acceptance for attributes related to color and grain shape. It was already established that in affective test, two groups of consumers were formed based on their acceptability, and for group two (Table 5), the flowered 'CAC' grains were equally accepted with CN and TN, followed by the 'AN' and 'EO' landraces.

Depending on their preference for the commercial presentation of the grains for *pozole*, consumers were divided into two groups: those who consumed industrially flowered grains (packaged in plastic bags) and those who nixtamalized the maize at home using the TN method. Individuals who reported consuming canned *pozole* maize did not significantly contribute to explaining the variability in the data.

Conclusion

The CN method resulted in a higher volume of flowered grain, shorter flowering times and softer grains. However, it also led to higher total dry matter loss and increased lightness compared to the TN method. One advantage of TN was that, due to its less aggressive processing conditions, it preserved the aleurone layer and some of the pigmentation in the 'EO' landrace flowered grain. For pigmented maize, CN would not be recommended. In addition, TN does not use additives (sodium hydroxide and sodium metabisulfite) that could cause health problems if used indiscriminately.

The 'CAC' landrace presented the best technological characteristics for flowered grains in both TN and CN. In terms of consumer preference, the flowered 'CAC' grains obtained with TN and CN were equally favored by group two consumers, followed by 'AN' and 'EO.' Consumers in group one, as well as the original group ($n = 100$), preferred 'CAC' with TN first and 'CAC' with CN last. This preference was influenced by attributes such as aroma of dough and nejayote and sweetness flavor. Conversely, the flowered grain obtained with CN had the lowest acceptance due to its sulfuric and acetic odor, as well as its sour taste.

The preference of the Cacahuacintle landrace for both nixtamalization methods is due to the geographical area in which the study was carried out, making this a limitation. It is likely that the results will be different in other areas, so it is suggested that other regions be explored and other landraces worked with.

This study underscores the significance of preserving traditional practices and highlights the importance of recognizing that consumer engagement with the specific maize landrace type of the nixtamalization process plays a crucial role in determining the final acceptance of the flowered grain for *pozole*.

The unrestricted use of additives in the nixtamalization process by the pozolero maize industry should be standardized and regulated by the competent authorities in order to guarantee safe products that do not pose a health risk.

Abbreviations

AHC	Agglomerative hierarchical clustering
AN	Ancho
CAC	Cacahuacintle
CN	Commercial nixtamalization
DML	Dry matter losses
EO	Elotes Occidentales
FI	Flotation index
FV	Flowered grain volume
HGW	Hundred grain weight
L*	Lightness
PF	Puncturing force
PLSR	Partial least squares regression
SI	Saturation index
TN	Traditional nixtamalization
TW	Test weight

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Author contributions
MGVC contributed to conceptualization, methodology, investigation, writing—original draft, visualization and supervision, AHM was involved in methodology, validation, formal analysis, investigation and data curation, NPR contributed to visualization, project administration, funding acquisition, resources and writing—review and editing, LGC was involved in data curation and writing—original draft, ARN contributed to methodology and validation, AM was involved in methodology and validation, and GPP contributed to investigation, methodology and formal analysis.

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Availability of data and materials
All data analyzed during the study are included in the published article. Data will be made available upon reasonable request.

Declarations

Ethics approval and consent to participate
All panelists gave their consent before starting the study.

Consent for publication
All authors agree for this publication.

Competing interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work featured in this paper.

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