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Research article

Flavor and TASTE attributes and nutritional insights of maize tortillas from landraces of Mexican races

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ABSTRACT

Maize tortilla is the best-recognized food product of Mexican gastronomy. Artisanal maize tortillas (AMT) are prepared with native maize varieties and a traditional process. The aims of this study were to identify sensory attributes, texture, and color in AMT that allow them to be differentiated from commercial tortillas, and to determine the chemical and mineral composition of both types of tortillas. Six landraces related to four Mexican maize races were used. Two commercial tortillas were included as references (*tortillería* and supermarket). Tortillas were subjected to sensory analysis by the modified Flash technique, texture and color were measured objectively and chemical and mineral analysis of all tortillas were evaluated. Lime taste and lime smell attributes were relevant to differentiate AMT from commercial tortillas; aftertaste and fracturability attributes were highly associated to supermarket tortillas. The fracturability attribute of tortillas is consider undesirable for taco preparation. Five of the six AMT were characterized by the presence of a layer, a characteristic that is associated with traditional tortilla made by Mexican consumer. Regarding chemical composition, supermarket tortillas exhibited the highest dietary fiber content (17.09%), but showed 30% more Na than AMT, with the exception of tortillas from Purepecha native variety. Besides, supermarket tortilla had 48.9% less Ca than AMT. The sensory attributes relevant to differentiate native maize tortillas from the commercial maize tortilla references were appearance, smell, and taste, while textural and color attributes played a lesser role.

1. Introduction

Maize tortilla is a foodstuff widely consumed in Mexico, where its daily consumption per person is 217 g in rural areas, and slightly less in urban areas (155 g) [1]. Tortilla and other products from nixtamalized maize grain constitute the food group with the largest

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total energy contribution to the Mexican population of five years of age and older people, accounting for 20.5% in the overall population, 28.6% in rural and 17.6% in urban populations [2].

Maize tortilla is prepared through the nixtamalization process. Nixtamalization is the alkaline ($CaOH_2$) cooking of maize grains followed by a steeping time that allows Ca to be absorbed by the grain [3]. This procedure brings about a modification of maize grain components that render a flexible masa for making flat tortillas. Currently, the maize tortilla commercial market in Mexico is made up of tortillas prepared from a mixture of fresh nixtamal dough and industrial nixtamalized maize flour in proportions of 50% each. This tortilla formula is the most sold in the small enterprises called "tortillerias". The tortillas made from nixtamalized maize flour exclusively are less popular and they are sold in supermarkets mainly [4]. Between these two types of tortillas, the most widely accepted by consumers is the tortilla from tortillerias [5]. The commercial tortillas sold in Mexico are prepared from maize grain produced with hybrid seeds in the northwest region of the country [6].

In recent years, the consumption of another type of tortilla has become relevant in big cities of the country. This is the tortilla prepared by the artisanal method of nixtamalization and using native maize grains exclusively. The price of this tortilla is higher than that of the commercial tortilla, and it is marketed in high-end restaurants and gourmet stores. This fact has begun to develop a market for the native varieties of several of the Mexican maize races recognized for their use in tortilla preparation. In this market, the direct connection between campesinos (small growers of native varieties) and processors is favored, and better prices are paid to the campesinos for their grain. The prevalence of these markets and their growth would greatly benefit the economy of small producers who are the ones who preserve the ancestral varieties of maize [7].

Commercial and artisanal tortillas are easily differentiated by their appearance, particularly when the latter is handmade [8]. However, if tortillas are made using mechanical machinery, as occurs in the gourmet tortillerias belonging to famous restaurants, the tortillas have homogenized thickness, diameter, and cooking time and it is difficult to distinguish between tortillas prepared with native maize from those made with commercial maize hybrids. Thus, it is necessary to use other criteria based on sensory properties as mentioned by Arnés et al. [9]. Some of this information has started to be generated [9,10], however, it is necessary to specify the

Table 1
Information about the maize landraces used in the study.

Maize races/ID	Origin (municipality and state)	Characteristics	Grain
Bolita (Bol)	Santa Ana Zagache, Oaxaca	Bolita race is highly distributed in the South region of Mexico, at medium and low altitudes [12].	
Cónico 1 (Con1)	Iztlahuaca, Edo. México	Cónico race is extensively disseminated in the medium and high valleys of Mexico. Maize production in these regions comes from landraces derived of this race.	
Cónico 2 (Con2)	San Martín de las Pirámides, Edo. México	Same than Con 1	
Pepitilla 1 (Pep1)	Cuetzala del Progreso, Guerrero	Pepitilla is consider as one of the best mexican race for tortilla production. Although, it has a more restricted distribution than Bolita and Cónico races.	
Pepitilla 2 (Pep2)	Apaxtla de Castrejón, Guerrero	Same than Pep 1.	
Purépecha (Purep)	Tingambato, Michoacán	This race is unique in the Tarascan plateau in Michoacán, which is the most productive area of maize in this state.	

attributes most related to native maize artisan tortillas. The nutritional benefits of the consumption of tortillas prepared with native maize landraces have been reported by several authors [1,10,11]. The conjunction of the efforts to spread information related to artisanal tortillas from native maize varieties could attract more consumers for this type of tortillas and reinforce a market for native maize varieties. The aims of the present study were: a) to identify the sensory attributes in native maize tortillas that allow them to be differentiated from commercial tortillas, and b) to evaluate the chemical and mineral analysis of both types of tortillas.

2. Materials and methods

2.1. Maize material

Five kg samples of six native landraces of white grain maize were used. Samples belong to the maize races Bolita (Bol), Cónico (Con), Pepitilla (Pep), and Purepecha (Purep). Detailed information about the landraces used is provided in Table 1.

Identification of the race corresponding to every sample was performed by maize landrace experts (Rafael Paczka, Flavio Aragón, and Alfredo Carrera). All the samples were cultivated under rainfed conditions, except the Con1 sample that was produced under irrigation. All samples of native landraces were harvested and shelled manually. Samples were stored in plastic bags and placed in hermetically sealed plastic containers until used. Two different commercial tortillas were used as references. The first one was obtained from a small *tortillería*, made with 50% fresh nixtamal dough and 50% nixtamalized flour, which will hereinafter be referred to as tortilla from *tortillería*, and the second tortilla was purchased in supermarkets and was 100% nixtamalized maize flour, which will be called supermarket tortilla.

2.2. Physical characterization of maize grain

All grain samples were characterized for: moisture content (M, %), test weight (TW, kg/hL), hardness, or flotation index (FI, %), weight of one hundred grains (100 GW, g), and proportion of floury endosperm in the grain (FE, %). These determinations were made according to the methodologies described by Salinas and Vázquez [12].

2.3. Nixtamalization and tortilla preparation

In order to standardize the nixtamalization process for the landraces used, several preliminary tests were carried out on cooking temperature and steeping time variables to reach an internal humidity of nixtamal close to 50%, which is considered necessary to achieve a fresh dough with an adequate texture for tortilla preparation [13]. Samples of 1.0 kg of grain, with 1% food grade lime (Nixtacal, Calidra, MX) (with respect to grain weight) and a grain:water ratio of 1:2 (*p/v*) were cooked in pewter pots. The cooking time was assigned according to the hardness of the grain measured by the flotation index [12]. The cooking times for landraces were as follow: Con2 and Purep were cooked for 30 min; Bol, Con1, and Pep1 were cooked for 35 min; Pep2 was cooked for 40 min. The steeping time was of 14 h and this process was performed in plastic bottles sealed and placed in a carton box in order to achieve slow cooling and improve the hydration of nixtamal. After steeping, the nixtamal was washed with water and ground in a stone mill (Molinos Arena, Tlaxcala, MX). The fresh dough obtained was kneaded manually adding purified water to achieve the texture required for molding. After kneading, the fresh dough was placed in the roller area of the tortilla-making machine (Tortilladora semi-automática Villamex, Jalisco, MX) (SFig. 1) used to make the tortillas. The baking of tortillas were made in hot metallic plates at 270 °C for 20 s each side. Freshly made tortillas were allowed to cool at room temperature for about 40 min and were then wrapped in cotton napkins and stored under refrigerated conditions.

2.4. Moisture content of nixtamalized products and tortilla color

The moisture content of nixtamal (NM), fresh dough (FD), and tortilla (TM) was evaluated with the method 985.26 [14]. The moisture content was also determined in the tortillas used as references (*tortillería* and supermarket). The tortilla color was determined with the Hunter-Lab (MiniScan XE Plus colorimeter model 45/0-L) in the CieL*a*b* scale using three tortillas. The color lecture was done in the tortilla layer opposite to the “blister” that forms after cooking.

2.5. Chemical and mineral composition of tortillas

Four tortillas per sample were cut into small pieces and placed on a metal tray, which was kept in the dark for 24 h at room temperature to dry the tortilla samples. The dried tortilla samples were ground using a cyclone mill (UDY Corp., USA) equipped with a 0.5 mm mesh. The ground samples were then placed in glass jars, sealed, and stored in the dark at −20 °C. The analysis included measurements of moisture, ash, fat, protein and total dietary fiber, according to methods 925.10, 923.03, 963.15, 920.152, and 992.16, respectively, as described in the AOAC [14]. The mineral analysis considered the determinations of Al, Na, Ca, Fe, Mg, and Zn after sample digestion with a diacid mixture (HNO_3– $HClO_4$. 2:1 *v/v*), Readings were performed in triplicate using an inductively coupled plasma triplicate atomic flame emission spectrophotometer (ICP-OES 725-ES; Agilent; Santa Clara, CA, USA) [15].

2.6. Tortilla texture

This attribute was determined in tortillas stored under refrigeration for 24 h. Before evaluation, the tortillas were reheated in sets of three, wrapped in cotton napkins, in a microwave oven at medium intensity (400 W) for 30 s. The hardness of tortillas (breaking force) was recorded with a Brookfield texturometer (ModelCT3. Middleboro, MA, USA), equipped with a 1/4-inch diameter spherical aluminum probe. The test conditions included a compression ratio of 40 mm (distance), pre-test speed of 1 mm/s; test speed of 1 mm/s and post test speed of 10 mm/s [16]. The tortilla was placed between two perforated plates with the opposite side to the “blister” formation. The force recorded when the sphere passed through the tortilla was considered as the breaking force, and was expressed in Newtons (N).

2.7. Sensory analysis

The modified flash profile technique was employed, using descriptors generated and selected by a group of evaluators. Defining the descriptors for sensory analysis of maize tortillas is one of the first steps in the evaluation process. To define these descriptors accurately, it is essential to understand the distinctive characteristics of the samples.

A total of twenty-two descriptors were utilized, categorized into appearance (4), texture (8), smell (4), taste (5) and aftertaste (1) (Table 2). The number of descriptors used in sensory studies of tortilla may vary. In this way, Palacios et al. [8] employed 33 descriptors in the sensory evaluation of corn tortillas produced through artisanal and commercial processes. Similarly, Arnés et al. [9] utilized 19 descriptors in their sensory evaluation of three tortillas with varying formulations and manufacturing processes, including one made from native maize and another using the artisanal process.

A detailed description of the attributes related to the appearance, texture, odor, and flavor of the tortillas was provided to the evaluators in a session before doing the evaluation. Fifteen evaluators (nine women and six men) aged between 20 and 27 years participated in the sensory evaluation. All of the evaluators signed the informed consent letter. Questionnaires were developed for the evaluation, containing a list of predefined attributes. The questionnaires were created using the FIZZ program, version 2.3 (Biosystemes, FR). The evaluation was conducted individually, following a monadic sequence and using a 9-point intensity scale ranging from 1 (lowest intensity) to 9 (highest intensity) [17].

The tortilla samples were coded with random three-digit codes and presented on white plastic plates for evaluation. The analysis was performed on tortillas stored for 24 h in refrigeration, which is the time and conditions under which the greatest changes in the tortilla aging process occur [18]. Before the evaluation, the tortillas were reheated in a microwave oven for 30 s at medium intensity (400W), in sets of two tortillas wrapped in a cotton blanket, inside a plastic bag. Once heated, the samples were placed on the plate and immediately evaluated.

2.8. Statistical analysis

Data from physical characterization of maize grain and tortilla, and the chemical composition of tortilla were subjected to ANOVA analysis under a completely random design with the use of SAS software (SAS for Windows, V9). A Tukey ($p \leq 0.05$) means comparison of treatments was run when required. Data from tortilla sensory evaluation were processed with the Procrustes Generalized Analysis (PGA) with the statistical software XLSTAT 2012, Addinsoft, version 10.0.

3. Results and discussion

3.1. Physical characteristics of grain

The variables related to grain hardness (TW, FI, and FE) showed values associated with grains of intermediate to soft texture, which are easier to cook and grind during the artisanal method of tortilla preparation (Table 3). The hardness of the grain is the result of the proportions of floury and horny endosperm, when the floury endosperm predominates, the grain is soft, on the contrary, if the horny endosperm abounds, the grain is hard [19]. The 100 GW ranged from 24 to 45.4 g, with the lowest values found in Con2 and Pep2

Table 2
Sensory attributes used to evaluate tortillas with the Flash Profile technique.

Appearance	Homogeinity surface	Smell	Fresh dough smell
	Presence of layer (blister)		Lime smell
	Color (cream to light-yellow)		Flour maize smell
	Presence of black zones (like roasted)		Corn on the cob smell
Texture	Rougness to touch	Taste	Fresh maize dough
	Moisture to touch		Lime
	Rollability		Salty
	Fracturability		Sweet
	Hardness		Feeling of dryness
	Cohesiviness	Aftertaste	Fresh dough aftertaste
	Adhesiveness		
	Chewiness		

Table 3
Physical characteristics of maize grain from native maize landraces.

Landraces	M (%)	TW (kg/hL)	100 GW (g)	FI (%)	FE (%)
Bol	10.7d	75.7a	45.4a	52.0b	75a
Con1	14.1a	74.6b	36.1b	49.0b	75a
Con2	12.2b	68.9f	24.0c	76.0a	75a
Pep1	11.7BCE	71.5d	43.7a	44.5BCE	75a
Pep2	11.9BCE	69.8e	26.3c	36.5c	50b
Purep	11.6c	73.4c	44.9a	76.0a	75a
MSD	0.53	0.52	3.5	9.5	0.0

M: moisture; TW: test weight; 100 GW: 100 hundred grain weight; FI: floatation index; FE: floury endosperm, MSD: minimum significant difference. Means in the same column followed by different letters are significantly different (Tukey, $p < 0.05$).

native maize varieties. This variation is comparable to that reported by Rangel-Meza et al. [20] in native maize varieties collected in Ecatlán, Puebla, México.

Among the physical variables of the grain, the ones that have the most significant impact on the nixtamalization process are 100 GW and hardness (FI). These variables influence the degree of grain hydration during the steps of alkaline cooking and steeping, which is reflected in the texture of the fresh dough and tortilla quality [21].

3.2. Moisture content in nixtamalized products and tortilla color

Nixtamal moisture (NM) differed significantly ($p < 0.05$) among the evaluated samples. Con2 and Purep samples exhibited the highest values, while the lowest NM was observed in the Bol sample (Table 4). These results may be influenced by the size and hardness of the grain samples. Based on their FI values, the maize samples Con2 and Purep had soft grain, with Con2 having the lowest 100 GW (Table 3). In contrast, the Bol sample had medium grain hardness, and was characterized by the highest 100 GW, indicating larger grain size. It is important to note that all samples, except Bol, had values equal to or greater than 50% of NM, which is necessary for easy nixtamal grinding and to obtain fresh dough with favorable texture characteristics for molding tortillas. When NM is less than 50%, the fresh dough can present coarse granulometry, resulting in hard and dry tortillas.

The nixtamal moisture (NM) levels in the analyzed samples fall within the range reported by Vázquez et al. [22] for native maize from the Mexican Altiplano. In Vázquez et al.′ study, the Cónico landrace exhibited NM values ranging from 45.7 to 48.0 %, while the Bol landrace in their study had the lowest NM value at 37.5 %. These findings align with the observations in the Bol landrace of the present study.

NM levels in maize grain can vary depending on nixtamalization conditions, such as cooking time, temperature, alkali amount, steeping time, and washing intensity [23]. However, the physical characteristics of the grain also play a role [22]. To evaluate the impact of the intrinsic characteristics of the grain on tortilla quality, it is essential to conduct standardized nixtamalization with consistent processing variables, as was done in this study.

The moisture of fresh dough (FDM) showed values from 59 to 61.8%, with the lowest values in Con2 and Bol samples; the highest values were observed in Pep1, Pep2 and Purep samples. These results are similar to those reported in native maize samples from the Mexican highlands [22]. The capacity of the fresh dough to absorb water depends on the physical (grain size and hardness) and chemical characteristics of the grain (starch content and proportions of amylose and amylopectin) [24].

The moisture of tortillas (TM) varied between 42.3 and 47.3%, and corresponded to Bol and Con2 samples, respectively. The moisture of the commercial tortillas used as references was higher by approximately five percentage points than that of the native maize tortillas, result attributed to the presence of carboxymethylcellulose (CMC) and other gums present in the nixtamalized maize flour (NMF) [25] that are added in order to improve water absorption and retention. Morales and Zepeda [11] observed similar moisture differences in favor of tortillas made with NMF in relation to fresh dough tortillas. The TM is associated with softness and a

Table 4
Moisture content in nixtamal (NM), fresh dough (FDM) and tortilla (TM) and tortilla color of samples from native landraces and the commercial tortillas used as references.

				Tortilla color		
Samples	NM (%)	FDM (%)	TM (%)	L	Hue (°)	Chroma
Bol	48.2b	59.6BCE	42.3b	69.5d	85.0c	31.7 ab
Con1	52.9 ab	60.7 ab	44.5 ab	66.8f	85.6BCE	28.6d
Con2	54.8a	59.0c	47.3 ab	67.7ef	85.3BCE	29.4cd
Pep1	50.6 ab	61.0a	43.0b	70.9c	84.9c	33.1a
Pep2	51.1 ab	61.8a	46.2 ab	70.9c	86.7 ab	29.6cd
Purep	54.6a	61.5a	44.6 ab	68.4de	84.8c	30.6BCE
Tortillería	NA	NA	51.4a	73.8b	87.8a	30.0bcd
Supermarket	NA	NA	50.7a	78.4a	85.4BCE	21.7e
MSD	4.9	1.2	7.2	1.3	1.6	2.0

NM: nixtamal moisture, FDM: fresh dough moisture, TM: tortilla moisture, L: luminosity. MSD: minimum significant difference. Means in the same column followed by different letters are significantly different (Tukey, $p < 0.05$).

sensation of dryness when chewing during sensory analysis. Besides, TM influences the tortilla yield, since to achieve grain: tortilla yields of 1.5 or more it is necessary that the TM be $\geq$ 45 % [21].

The thickness of the tortilla also influences its moisture content. When it is made under the traditional procedure which implies its manual molding, the tortilla thickness is 3–4 mm [20], that is greater than that of the commercial tortilla (1.3–1.5.0 mm). According to the study by Palacios et al. [8], the moisture of tortillas made by women of a community of San Cristóbal de las Casas, Chiapas, Mexico from maize of the Olotón race with white and yellow grain, varied between 32.8 and 33.9 %.

Of the color parameters, the luminosity (L) or brightness ranges from 0 for black, and 100 for white [26]. According to this scale, the supermarket tortilla was the brightest while Cónico race tortillas were the darkest. The color among native maize tortillas was different. The brightest tortillas were those of Pepitilla maize (Pep1 and Pep2) as they presented high percentages of brightness (L). The commercial tortillas, both from *tortilleria* and from the supermarket, presented the highest values of L; therefore they were more luminous than any of the native maize tortillas. This result is attributed to the fact that NMF is whiter than any fresh dough from maize grain landraces, since the industrial nixtamalization process uses less amounts of lime than the traditional method [27].

The Hue color parameter refers to the tint of the color and it represents the dominant color perceived by the observer [26]. Based on the Hue values observed in the tortillas, their color is yellow, but in combination with the L values, the tortillas showed a light yellow color that can be assumed as creamy. The chroma color parameter measures the saturation index of color, and by de values observed in the tortillas, the color of them could be described as vivid, not with shades of grey.

The native maize tortillas most similar in color to commercial tortillas were those made from Pep2 maize. The color of the tortilla is an attribute associated with its appearance, which influences consumer acceptance. Some people prefer white tortillas [10], but for others color is less important than aspects such as freshness, flavor, and flexibility [5].

3.3. Chemical and mineral composition of tortillas

The chemical and mineral composition of the tortillas is presented in Table 5. The ash content varied between 1.68 and 2.03 %, values that corresponded to the Bol and Pep1 tortillas, with the lower value, and that of *tortillería*, with the highest value. The high ash content in tortillas from *tortillería* could be related to the practice of adding lime directly to the fresh dough, a practice that some tortilleries do, in order to extend the shelf life of fresh dough and tortillas by increasing the pH. Ash content in tortilla represents all the grain minerals that remain after the nixtamalization process, to which is added the calcium and other trace minerals (Mg, Fe, and Zn) present in the lime used in the nixtamalization of the grain [28].

Protein content of tortillas varied between 9.15 and 12.91 %, values that corresponded to the Bol and Con1 maize tortillas, respectively. The Cónico maize tortillas showed the highest protein content, followed by Pepitilla, Purepecha and Bolita. The observed values are greater than the interval of 8.88–9.07 % reported by Morales and Zepeda [11] in commercial tortillas from Mexico City made with fresh dough.

In tortillas, the oil from the germ of the grain represents fat content. This component in tortillas varied from 0.96 to 6.99 %, with extreme values in supermarket and Purep tortillas, respectively. The low oil content in commercial tortillas can be attributed to the NMF presented in their formulation, During NMF production, efforts are made to eliminate germ component as much as possible with the intention to favor the shelf life of the product. Morales and Zepeda [11] also reported a lower oil content in NMF tortillas compared to fresh dough tortillas. The high oil content of Purep tortillas could be explained by the size of the kernel in this maize, which was one of the largest in this study. A larger kernel maize size is associated with a higher proportion of germ and oil [29].

The dietary fiber values were between 12.38 and 17.09 %, and corresponded to Bol and supermarket tortillas, respectively. The high fiber content in the latter stands out, which could be associated with the presence of the gums added to the NMF. The dietary fiber values observed in native maize tortillas are slightly below the range reported by Morales and Zepeda [11] of 14.5–14.9 % for commercial fresh dough tortillas.

Of the minerals present in the maize tortilla, Ca was the most abundant while Al was the least rich. Ca is an essential mineral in human diet as it participates in multiple biological functions, while Al is required in minimum amounts (less than 10 mg/day). Moreover, high intake of aluminium has been related with some neurological diseases such as Alzheimer's, Parkinson's and Autism

Table 5
Chemical and mineral composition of tortillas from native maize landraces and the commercial tortillas used as references.

Tortillas	Chemical composition (%)					Mineral composition (mg/100 g)					
	Ash	Protein	Oil	TDF	Carboh	Al	Na	Ca	Fe	Mg	Zn
Bol	1.68d	9.15b	2.59cd	12.38b	74.21a	0.89e	87.04bcd	224.9c	2.69ef	93.83d	1.32d
Con1	1.89b	12.91a	2.81BCE	13.24b	69.13b	1.46b	86.70bcd	187.7e	2.92de	95.32BCE	1.80c
Con2	1.76bcd	12.58a	2.03d	15.00 ab	68.62b	1.28c	74.51e	206.0d	3.69c	93.28d	2.05c
Pep1	1.68d	11.41 ab	2.27cd	14.98 ab	69.65b	0.859e	81.31de	236.9b	2.38f	86.49f	1.80c
Pep2	1.76cd	11.19 ab	3.45b	14.32 ab	69.29b	1.41 cb	84.24cde	297.2a	2.98de	97.89a	2.04c
Purep	1.74cd	10.87 ab	6.99a	14.21b	66.18b	1.40BCE	95.95b	223.0c	3.07d	95.66b	1.44d
Tortillería	2.03a	9.61b	1.24e	12.92b	74.20a	2.28a	94.75BCE	293.2a	4.86b	91.26e	2.70b
Supermarket	1.83BCE	11.22 ab	0.96e	17.09a	68.89	1.10d	116.95a	117.1f	8.85a	94.03cd	4.20a
MSD	0.13	2.57	0.73	2.87	4.01	0.16	10.7	6.8	0.32	1.43	0.3

TDF: total dietary fiber; Carboh: carbohydrates, calculated by difference, MSD: minimum significant difference. Means in the same column followed by different letters are significantly different (Tukey, $p < 0.05$). Data expressed in dry base.

[30].

The Ca values varied between 117.1 and 297.2 mg/100 g DM, and corresponded to supermarket and Pep2 tortillas, in that order. Supermarket tortilla had 60% less Ca than *tortilleria* tortilla and 48% less than the average of Ca in native maize tortillas. The low Ca content in supermarket tortillas is related to the low amount of alkali in the nixtamalization step, during the process of making NMF, and the grinding and screening processes aimed for removing the greatest amount of pericarp in order to get a whiter NMF [8]. The differences in Ca among native maize tortillas can be attributed to the amount of pericarp retained after rinsing the nixtamal, which is affected by both genotype and the nixtamalization process conditions.

The yellowness tone of color in tortillas is commonly associated with a higher level of alkali used during the nixtamalization process and with a higher Ca content. Fig. 1 shows the tortillas from native maize varieties (Fig. 1A) and the commercial tortillas (Fig. 1B). A low yellowness tone is appreciated in the supermarket tortilla (Fig. 1Bd), which has the lower Ca content.

The Ca data obtained in the tortillas are similar to the value of 289.6 mg/100 g reported by Moreno et al. [31] for tortillas made using the traditional process from fresh dough. In nixtamalized grain, Ca is concentrated in the pericarp and germ and its content is affected by the amount of lime used in nixtamalization and the duration of the steeping time [32].

The Na content obtained in supermarket tortillas stands out, which was on average 27.4% higher than the values of native maize tortillas. This difference could be attributed to the gums added to the NMF (nixtamalized maize flour), particularly carboxymethylcellulose, which is a sodium salt [33].

The Fe concentrations varied between 2.38 and 8.85 mg/100 g, with the lowest value for Pep1 tortilla and the highest value (8.85) observed for "Supermarket", according to Table 5. These results are lower than those reported by Pappa et al. [28] for traditional maize tortilla (44.1 mg/100 g of wet base). The supermarket tortilla presented an average of 66% more Fe than the native maize tortillas, while the tortilla from *tortilleria* was 39 % higher in this mineral. The higher Fe concentration in commercial tortillas can be ascribed to the supplementation of this mineral that NMF companies carried out to comply with the current regulations in Mexico for this type of product. The Mg concentration showed similar values between the tortillas analyzed, both from native maize and commercial ones. The values obtained in this mineral were lower than that reported by Moreno et al. [31] for commercial maize tortilla (138.3 mg/100 g) made under the traditional process. The native maize tortillas had an average of 35.3 % and 58.5 % less Zn than the tortilla from *tortilleria* and supermarket tortilla, respectively, results related to the supplementation of this mineral in the NMF.

3.4. Tortilla texture

The breaking force (BF) of tortillas was different among the samples evaluated. The lowest values were registered in the *tortillería* one as well as in the supermarket sample, which are commercial tortillas. The highest values corresponded to samples Bol, Con1, and Pep1. In tortillas from native maize landraces, the order of the BF was Cónico > Bolita > Pepitilla > Purépecha (Fig. 2).

A low BF is related with a soft tortilla. However, a good quality tortilla has to be soft and resistant enough not to break when a stew is poured over on for having a taco [34].

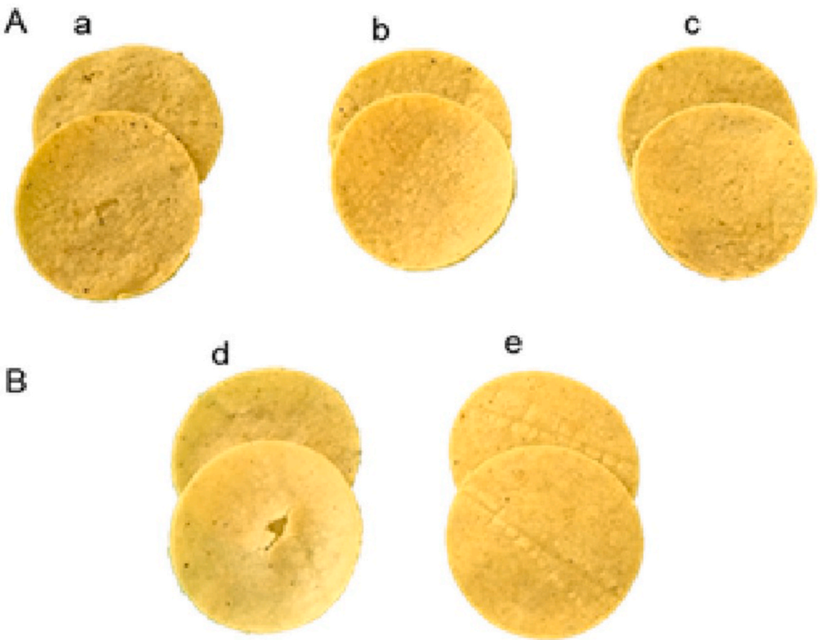

Fig. 1. Tortillas from native maize varieties (A), a: tortillas from Con2, b: tortillas from Pep2, c: tortillas from Purep, and commercial tortillas (B), d: supermarket tortilla, e: *tortillería* tortilla.

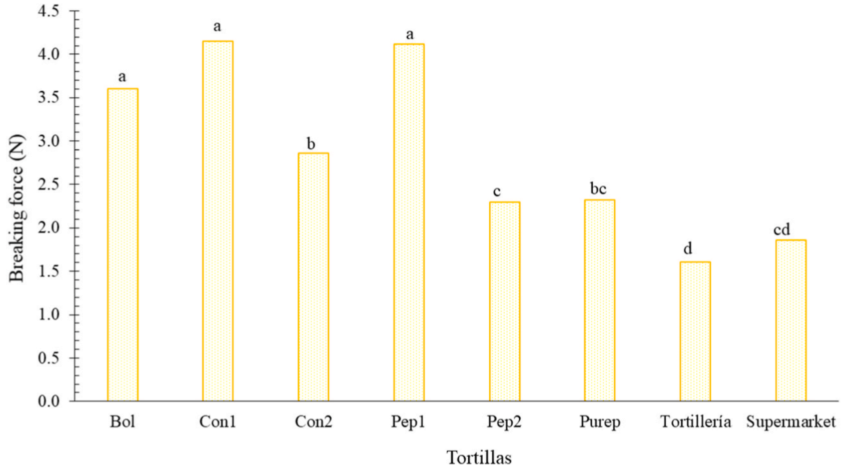

Fig. 2. Breaking force in native maize landraces and commercial tortillas evaluated with the Brookfield texturometer. Means followed by different letters are significantly different (Tukey, $p < 0.05$).

The softness of tortillas is a quality attribute for consumers, and the processed food industry satisfies this requirement by adding gums to the NMF where these types of additives have been detected [25]. However, it could have a negative impact on the health of consumers, since the high intake of this type of additives causes alterations in the intestinal microbiota and favors inflammatory processes, many of them linked to diseases of the type called "chronic degenerative diseases" [33].

3.5. Sensory evaluation of tortillas

Fig. 3A shows the principal component analysis obtained through a Generalized Procrustean Analysis (GPA) for the appearance and texture attributes of the tortilla profile. The GPA eliminates differences in scale, concept, and rater biases toward a particular concept among variables, and allows for principal component analysis (PCA). The results show that the two first components explain 57.5% of the sample variability.

Positively correlated with component 1 (C1) were the tortillas Con1, Purep, Bol, Pep1 and Con2; the Con1 and Purep tortillas were characterized by an appearance with the presence of a layer (the face of the "blister" clearly visible), hard, chewy and cohesive texture. The presence of a layer in the tortilla is associated with traditional made tortilla by the Mexican consumer. Bol, Pep1 and Con2 tortillas presented black zones on their surface, intense yellow color and rough texture. Another correlated attribute is the hard texture that is important so that tacos can be made without breaking the tortilla. The hardness or resistance of the tortilla is also relevant to be able to use it as a spoon in dishes with broth; other characteristics correlated with these tortillas were chewiness and cohesion, these last characteristics directly correlated with hardness.

On the other hand, the Bol, Pep1, and Con2 tortillas showed black areas on their surface because for these varieties the heat applied

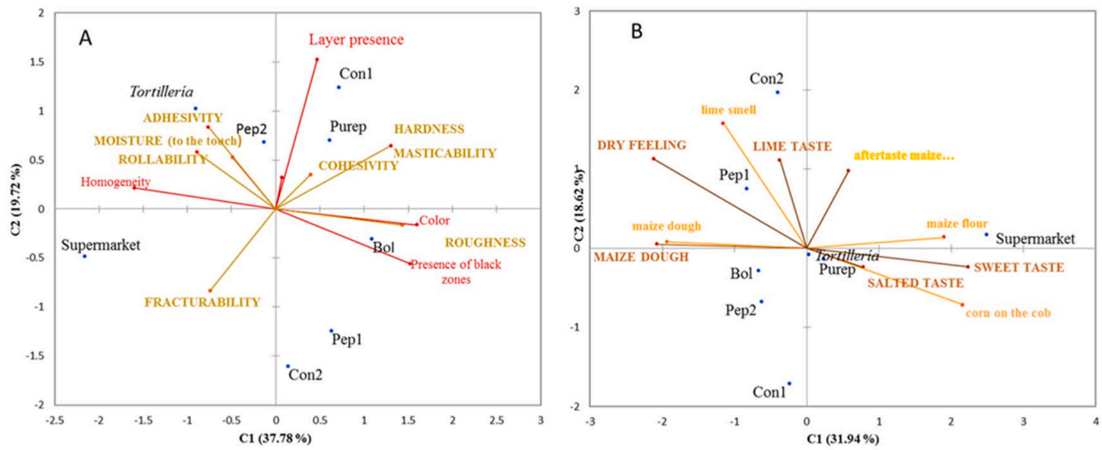

Fig. 3. Generalized Procrustes analysis (GPA) map showing the relative sensory positioning of **appearance** and **texture**, of maize tortilla samples (A) and the relative sensory positioning **TASTE**, **smell** and **aftertaste** of maize tortilla samples (B) obtained from the modified flash profile (mFP). The GPA plots were obtained from the mFP consensus data.

during cooking burned parts of the tortilla. They had an intense yellow color that coincides with high values of Hue measured instrumentally (Table 4), and rough texture. These two characteristics (intense yellow color and rough texture) have already been recorded in native corn tortillas made with artisanal processes, which appeared uneven in color and surface and were rougher than commercial tortillas made with mixtures of fresh masa and NMF [8,10].

The supermarket tortilla was correlated with the fracturability attribute, being the tortilla with the highest intensity in this attribute. Fracturability can be considered as a defect in the tortillas since it does not allow the preparation of the taco.

The Pep2 and tortilla of *tortillería* were found to be negatively correlated to C1 and positively to C2, characterized by their homogeneous appearance, sticky texture and moisture to the touch. These last two attributes are directly correlated, that is, the higher the moisture, the higher the tortilla stickiness. On the other hand, the high rollability shown is a characteristic that allows the tortilla to be rolled to make the taco and is associated with adequate nixtamalization of the maize, in addition to being an attribute that the consumer seeks to find in the tortilla [35].

Fig. 3B shows the results of the attributes of odor, flavor and taste of tortillas. Both components (C1 and C2) explain 50.56% of the samples variation. Positively correlated to C1 was the supermarket tortilla, which was characterized by a smell of corn flour and an aftertaste of dough, attributes that the Mexican consumer does not want to find in a tortilla, and that it has been associated with the use of NMF [10]. *Tortillería* and Purep tortillas were grouped near the origin, and thus not defined by any of the measured attributes, with the exception of salted taste.

Negatively correlated to C1 were the tortillas Con2, Pep1, Bol, Pep2, Con1, and Con2, characterized by smell and flavor attributes of lime and nixtamalized maize dough. Attributes that consumers associate with the identity and quality of tortillas [9], as well as by the sensation of dryness in mouth.

According to the results, the taste and smell of lime were perceived with greater intensity by the evaluators in the Con2 and Pep1 tortillas, even though all the maize samples were nixtamalized with the same amount of lime (1%). The evaluators identified the smell of maize and nixtamal in all the native maize tortillas evaluated, except for the Purépecha maize (Purep), in which a smell of corn on the cob predominated.

The smell attributes of maize and nixtamal have been identified in maize tortillas of the Olotón race prepared under an artisanal process, but not in the commercial tortilla made from a mixture of NMF and fresh nixtamal dough [8], which agrees with the results of this study. However, Iuga et al. [10] did not identify the smell and flavor of lime in artisanal tortillas, but rather in tortillas made industrially from NMF. The sensory evaluation technique used by Palacios et al. [8] was called CATA (Check-All-That-Apply) while Iuga et al. [10] used a group of nine semi-trained evaluators, all of them Gastronomy students. The difference in the sensory techniques used possibly explains the lack of coincidence between both studies.

The *tortilleria*, and Purep tortillas were perceived by the evaluators as having a slightly salty taste, a result that is attributed to the presence of salts in the maize grains, since no salt was added during tortillas manufacturing. Curiously, these tortillas were the ones with the highest Na content (Table 4). The sweet taste was also perceived in these tortillas, but it was more intense in the supermarket tortilla, made 100% with NMF. The sweet-salty taste was not perceived in the rest of the native maize tortillas, contrary to what was reported by Iuga et al. [10] in which the sweet taste was more pronounced in the artisanal tortillas, concerning the commercial ones made from a mixture of nixtamal dough and NMF or 100% NMF. The sweet taste of tortillas comes from the soluble sugars that the grain possesses, concentrated mainly in the germ [19], whose content varies between maize varieties.

In summary, based on smell, taste, and aftertaste attributes, the commercial tortillas used as references and the Purep tortillas were similar to each other, and different from the rest of the tortillas. It is interesting to appreciate that the tortillas of the two Cónico maize landraces, although they were distributed in the same hemisphere of the component plane, they were assigned in opposite quadrants. The Con1 tortillas were evaluated as harder than those of Con2; none of the tortillas of this race were distinguished by their rollability. The differences observed in the two Cónico maize populations could be attributed to the characteristics of their grains, and not to differences in the preparation process, which was the same for both samples, except about cooking time, which was adjusted according to the hardness of the grain.

For the Pepitilla race, the sensory quality of the tortillas from the two landraces evaluated was contrasting, as they were located in different hemispheres and quadrants of the principal components plane. The Pep2 tortilla was characterized by its moisture to the touch, moisture in the mouth and rollability, in addition to having a homogeneous appearance, while the Pep1 tortilla was dry and hard, rough and heterogeneous in appearance. The differences in sensory quality between the Pepitilla maize landraces could be due to the physical characteristics of their grains. Pep1 presented a larger grain than Pep2, which could have affected its hydration during the nixtamalization process. Since grain quality is currently not paid for, farmers seek to increase the yields of their native maize by crossing them with other maize varieties with higher yields, and grain size considering this is one of the main components of this variable [36]. The high diversity of maize in Mexico is explained from the close relationship of each maize landrace with a particular food product, so it is relevant to preserve the original landrace of each race, because those characteristics allow us to achieve the qualities of those traditional dishes.

Additionally, the evaluators identified differences in the attributes considered, among the native maize tortillas, by placing the Pep2 tortillas as the only ones with characteristics of homogeneity, rollability, adhesiveness, and roughness to the touch, similar to commercial tortillas, but without the fracturability characteristic, which is an undesirable attribute for consumers. It is relevant that Pep2 tortillas presented these sensory qualities without having any added additives, in addition to presenting the characteristic aroma of nixtamal dough, which consumers appreciate in artisanal tortillas.

4. Conclusions

The analysis of maize landraces revealed marked uniformity in the physical characteristics of the grain, particularly in terms of grain hardness, demonstrating consistent maize quality for traditional tortilla preparation across various maize races. Nonetheless, notable differences emerged in both physical and chemical properties when comparing native maize tortillas with their commercially produced counterparts.

The sensory analysis technique used allowed to identify the native maize tortillas from the commercial maize tortilla references, based on appearance, smell, taste, and texture attributes. The attributes of smell, taste, and aftertaste accepted by Mexican consumers were positively evaluated in native maize tortillas, results that can help boost the consumption of tortillas prepared from native maize landraces and with the traditional method of making tortillas.

Further research is needed to identify additional distinguishing attributes that can empower consumers to readily discern native maize tortillas from their commercial counterparts. Such studies can contribute to the preservation of traditional maize landraces and their cultural significance in Mexican gastronomy.

Data availability statement

The data of this manuscript will be available if they are required.

CRediT authorship contribution statement

Y. Salinas-Moreno: Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization. **A. Gálvez-Mariscal:** Writing – review & editing, Supervision, Methodology. **P. Severiano-Pérez:** Writing – review & editing, Methodology, Data curation. **G. Vázquez-Carrillo:** Validation, Methodology, Formal analysis. **L.L. Trejo-Téllez:** Methodology, Formal analysis.

Declaration of competing interest

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

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e28314.

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