Journal of Ethnic Foods

ORIGINAL ARTICLE Open Access

Nixtamal techniques for different maize races prepared as tortillas and tostadas by women of Chiapas, Mexico

Gabriela Palacios-Pola[1,2*], Hugo Perales[1], Erin I. J. Estrada Lugo[1] and Juan de Dios Figueroa-Cárdenas[3]

Abstract

Nixtamalization, which means cooking maize in alkaline water, is the central technique for the culinary use of maize in Mexico and Central America. Without this procedure, relying on maize as the basic starch staple is inadequate because of nutriment deficiencies. Mexico has more than 50 principal racial types of maize, and these differ in grain qualities that can require the adjustment of the nixtamalization process. Properties such as hardness and grain composition influence nixtamalization because they are related to the absorption of water that occurs during cooking and steeping. Some maize preparations, like tortillas and tostadas, can also require the adjustment of nixtamalization to obtain a high-quality foodstuff. We studied how women in three regions of the state of Chiapas, which differ in the prevalent maize race available, prepare their nixtamal and whether they make changes according to the type of food they prepare. Interviews of 30 women follow the measure of relevant variables when the women prepared nixtamal. We found that nixtamalization is adjusted for different grain hardnesses and for environmental conditions. Variations were found in the cooking time of the nixtamal, in the amount of time the nixtamal was steeped, and in a special process of double boiling of the nixtamal performed by some women for tostadas. Women that specialize in production for the market have developed variations preferred by consumers. As practiced by women in Chiapas, nixtamalization is a flexible technique that is adjusted for maize type and for food preparations.

Keywords: Nixtamalization, Grain hardness, Native maize, Maize races

Introduction

Hundreds of dishes have been documented in Mexican cuisine for maize (*Zea mays* L., subsp. *mays*), including tortillas (the staple flat bread), gorditas (a thick flat bread), tostadas (toasted tortillas), tamales (a steamed preparation), atole (a hot thickened beverage), pozol (a cold beverage) and other maize-based preparations that may have favored its diversity as a crop [1–3].

About 60 native races and hundreds of landraces of maize are grown in Mexico [4, 5]; these have important variations in their grain qualities and nutritional characteristics and also in their culinary and gastronomic characteristics [6, 7]. In Mexico, the central technique that links maize and its culinary use is nixtamalization [1,8.]. Tortillas are the main foodstuff derived from nixtamal and the basic component of the daily diet of Mexicans; these Mexican cuisines have been recognized as intangible heritage of humanity [9]. Inside of Mexico the tortilla is recognized as an ethnic food, and in Central America and southern USA it is a common foodstuff [10].

Nixtamalization and its variation at the household level and for specific preparations, however, have been scarcely studied ethnographically [11]. The women of Ixtlahuaca and Tlaxiaco (regions of the State of Mexico and Oaxaca, respectively) make tortillas for their own

*Correspondence: gabriela.palacios@unicach.mx
[2] Universidad de Ciencias y Artes de Chiapas (UNICACH), Ciudad Universitaria, , Libramiento Norte Poniente 1150, Col. Lajas Maciel, Tuxtla Gutiérrez, 29039 Chiapas, CP, Mexico
Full list of author information is available at the end of the article

consumption and sale in public squares and markets. They cook hybrid and native varieties of maize, but they prefer the native grains by the shorter cooking time and better organoleptic characteristics of the tortillas [12, 13]. The discovery of nixtamalization was essential for developing a food culture around maize. Without nixtamalization, the nutritional deficiencies of this kernel would have prevented a diet based on this grain [8, 14]. Nixtamalization increases the calcium content and efficiency in the assimilation of essential amino acids, releases the available niacin and removes the kernel coating making the masa (dough) less fibrous and more elastic [15].

Despite the importance of fresh nixtamal in the Mexican diet, practically all scientific attention on nixtamalization has been focused on the production of industrial nixtamal [16–19]. Since it is a relatively simple process, formal research regarding homemade nixtamalization has been neglected. There is, however, a complexity hidden in its apparent simplicity that can be relevant for high-quality maize products.

In their simplified form, the maize kernels are cooked in alkaline water until the pericarp comes off [20]. The nixtamal, as the maize is called once cooked this way, can cool in the cooking liquid for several hours, commonly overnight. Next, it is washed one or more times in water and milled into a dough known as masa [21]. It is thought that early nixtamalized maize was done with wood or seashell ashes [11, 14]. Currently, the predominant form of alkaline used is calcium hydroxide ($Ca(OH)_2$ or lime) [22–25]. The cooking time of the nixtamal is commonly between 30 and 45 min, but it may be longer than 1 h or may be only steeped in boiling water but with a larger concentration of lime [25, 26]. After cooking, the nixtamal can be left to soak in its water from less than 30 min to 1 day [20].

Exploratory work has suggested the variation of interest in all steps of nixtamalization. Some nixtamalization processes are associated with a particular product, such as very short steeping for totopos (a tortilla-type food dehydrated with infrared radiation in a bottomless clay oven called comixcal) in the state of Oaxaca [27]. It may also be important to modify nixtamalization for some characteristics of the kernel, such as hardness and the predominant type of endosperm [28, 29].

Hardness and starch composition are characteristics that affect nixtamalization because they are related to water absorption when cooking and steeping the grain [29, 30]. Starch granules can be polygonal with a rigid protein matrix or spherical with a weak protein matrix; the former has smaller spaces [31]. Softer grains with larger spaces between starch granules enable faster water absorption.

In Mexico, women have been directly responsible for nixtamalization and have inherited the knowledge of how to nixtamalize from their families [32]. This work is of an ethnographic nature and examines how women in three regions of the state of Chiapas perform and use nixtamalization, as well as focusing on the variation of the process for three types of maize and two important food uses: tortillas and tostadas.

The quality of the tortillas was studied using two nixtamalization times [33] and the quality of the toasts through two cooking processes (in press); both are important products in most regions of Mexico. Artisanal tortillas and tostadas are highly demanded and appreciated; many women in need of income produce these for sale in markets and locally [34]. We expected that women distinguish between different types of maize and adjust the nixtamalization depending on the hardness of the kernel, while increasing the boiling time for the hardest grain for tortillas and tostadas. We also expected that women modify nixtamalization based on the type of food product prepared.

Methods

Study regions

The research was performed in 10 rural communities of 7 municipalities (Table 1, Fig. 1). We chose to work in three regions of the state of Chiapas, Mexico, with distinct altitudinal ranges that correlate neatly with the presence of the three maize races included in the study. In the three regions, women produce tortillas and tostadas for home consumption and some also for the market.

Native maize types

More than 20 races of maize have been reported for Chiapas [35], but only about 10 are common. In addition, the three studied, Tuxpeño, Comiteco and Oloton, stand out in abundance throughout Chiapas [36]. Maize races are a widely used informal taxonomic level for maize diversity; these commonly present subracial and interracial variants where they are prevalent [37].

Tuxpeño is a race with widespread distribution in warm regions of Mexico below 1,200 m.a.s.l. and is distinguished by medium-to-long cobs (15 to 20 cm) with a cylindrical shape. Their kernels are long and thin, commonly with a pronounced depression at the distal of the kernel. The Comiteco race has long cobs (sometimes more than 35 cm), is conical in shape and is the most important maize race in the Meseta Comiteca region (subsequently Comiteca). Oloton is the race that predominates in the temperate elevations above 2,000 m.a.s.l. [35, 36]. Its cobs are also conical in shape and commonly have disordered basal rows. The kernels tend to be spherical and short in length [38]. The Altos

Table 1 Characteristics of the communities included in the study

Region	Municipality	Community	Main maize race	Altitude	Population	Interviews
Metropolitana	Suchiapa	Pacú	Tuxpeño	449	2440	5
Metropolitana	Tuxtla G	Copoya	Tuxpeño	840	8160	2
Metropolitana	Berriozabal	Berlín	Tuxpeño	980	410	3
Comiteca	Comitán	F. Sarabia	Comiteco	1552	1673	1
Comiteca	Comitán	Yalumá	Comiteco	1740	2368	5
Comiteca	Comitán	A. Rodríguez	Comiteco	1914	855	1
Altos	Teopisca	Campo Santiago	Oloton	1918	553	5
Altos	Zinacantán	Pasté	Oloton	2279	3771	2
Altos	San Cristóbal	San José Buenavista	Oloton	2300	315	4
Altos	San Cristóbal	Carrizalito	Oloton	2365	59	2

Source: [45]

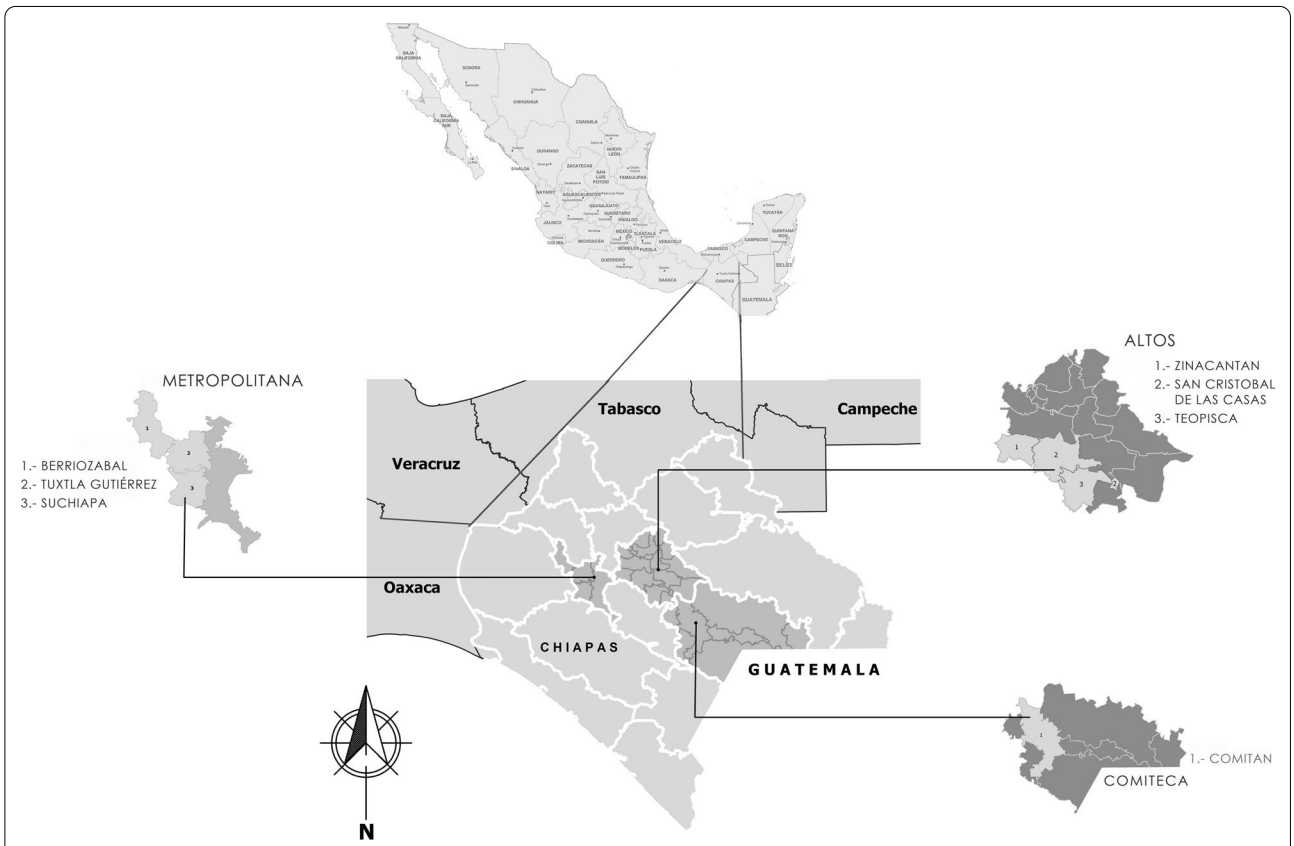

Fig. 1 Regions of study in the state of Chiapas and the state's location within the Mexican Republic. Mexican Republic map extracted from https://www.google.com/maps/@24.3228708,-100.130783,5z, copy edited in locating the three regions in Chiapas from https://earth.google.com/web/search/. Tuxtla Gutiérrez in Metropolitana can be located at latitude 16°45′20″N and 93°06′44″W, San Cristóbal de las Casas in Altos can be located at latitude 16°44′12″N and 92°38′18″W, and Comitán in Comiteca can be located at latitude 16°15′04″N 92°08′03″W

or highland region is between 1900 and 2400 m.a.s.l. and has a temperate humid climate, with Oloton as the dominant maize race. The Altos region is characterized by having a predominantly population of indigenous people (68%). The Metropolitana and Comiteca regions' population is mostly mestizo, but indigenous communities are also present (Fig. 2).

These three races have been reported to have different kernel hardness [39]. In anecdotal observations, the

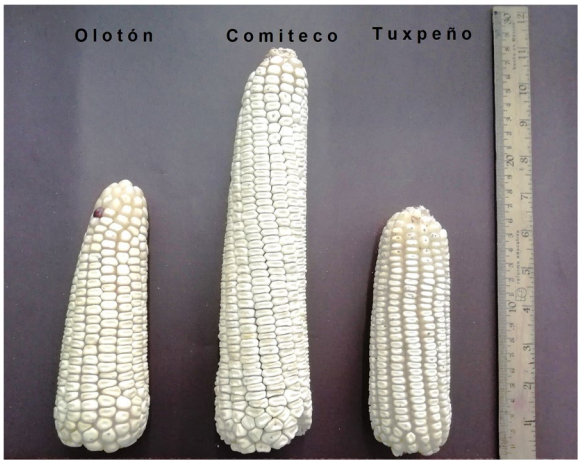

Fig. 2 Three types of maize: Oloton, Comiteco and Tuxpeño

Oloton has a harder kernel than Tuxpeño and Comiteco, which appear to be of intermediate hardness. In the literature, it is reported that Tuxpeño is harder than the Oloton [39]. In measuring the hardness and the compaction of the kernel associated with this research, we found that the Oloton and Comiteco tend to be harder than the Tuxpeño, but this was not systematic for the three independent samples collected for each race. Hardness, measured by the flotation index, results in 41 grains of 100 floating for Oloton, 36 for Comiteco and 35 for Tuxpeño. Test weight measurements as an indicator of hardness range between 76 and 77 kg/hL for the three races of corn. On the other hand, the hardness as a puncture force measured in Newtons (N) presents values of 123 N for Oloton, 124 N for Comiteco and 110 N for Tuxpeño. Since a significant variation was found within of each race, this measurement must be taken with a larger independent sample.

Interviews with women

To access the communities, we introduced ourselves to the local authorities, explained the purposes of the study and requested permission to work. We individually asked 30 women whether they wanted to collaborate in the project and for permission to be interviewed. We sought those that belonged to different neighborhoods and family nuclei to reduce kin relationships. Women were shown samples of kernels corresponding to maize of the three races studied to discuss their knowledge of each type of maize.

The interview guide applied was structured on their knowledge about maize races, differences between of grain types and colors when nixtamalizing, how they learned and at what age about the techniques of nixtamalization, and tortilla and tostada preparations.

In the Metropolitana region, five of the women sell tortillas for a living. Some of them also sell dough (masa) for pozol, and the other 5 are recognized for making good tortillas, although they do not produce them for market. No commercial tostada producers were found in this region, but all women produce these for household consumption. In the Comiteca region, all women prepare tortillas and tostadas for home consumption, and the five women of Yalumá are dedicated to the sale of these foods. In the Altos region, the women make tortillas for family consumption, and all but two make tostadas for sale.

Participant observation of nixtamalization

We participated with each of the women when they performed the nixtamalization of maize, as well as the subsequent making of their tortillas and tostadas. For this purpose, a participant observation guide with specific questions was used to identify how they perform the nixtamalization technique, how they acquired the knowledge and what they know of nixtamalization with respect to the race and hardness of the kernel, as well as its relationship with the type of food preparations and its characteristics. We also measured several relevant variables of the process: amount of corn, water and lime used; temperatures and cooking time of the nixtamal for tortillas and tostadas; resting time of nixtamal; washing; size and weight of raw and cooked tortillas and tostadas.

Results and discussion

Nixtamalization

The average age of women was 48.1 years (SD 13.7), varying between an average of 46.1 years in Altos and 55.7 years in Comiteca.

All the women interviewed learned to nixtamalize and make tortillas and tostadas from other women. They learn at a young age, and the practice is transmitted informally by adult's women. Same situation as in the case of Malawian girls who make "nsima", a kind of thick porridge prepared with corn flour [40].

Almost all (93%) learned from their mother or grandmother, and the rest from their mothers-in-law. The way they learned is through imitation, and they began with preparing tortillas. When mothers or grandmothers prepare the tortillas of the day, they provide a small portion of masa for young girls to participate. As one woman stated "leaving school they would make me make my *tortilla* … they gave me my little ball of *masa* to learn how to make my *tortilla*…".

No women stated that men prepare nixtamal or participate in preparing tortillas or other foods because it is considered a female activity [41]. If they require help to

carry heavy pots, some men in the family help with this activity. Other exception is public mills, which are mostly operated by men.

For nixtamalization, the women interviewed did not give us a specific description of how they learned to do it. Apparently, it is learned by imitation and without specific recommendations regarding the amounts of maize, water, or lime. Common practice is to add enough water to cover the kernels, so when the nixtamal boils and the water is absorbed by the grain, nixtamal will still be in solution. A small unmeasured quantity of lime is added to the water, and the maize is brought to a boil and cooked until the pericarp comes off when rubbed with the fingers.

The boiling temperature at the Metropolitana region is 5 degrees higher (average 97.5 °C) than in the other two regions (92.7 and 91.0 °C for Comiteca and Altos, respectively). The boiling time in the three regions ranged from 35 to 110 min, with a trend to shorter times in the Metropolitana region (Table 2). The average cooking time was 51.4 min in the Metropolitana region (ranging from 35 to 65), 72.1 min for Comiteca and 80.0 for Altos (ranging from 60 to 85 and 45 to 110, respectively).

Only one-third of women identified problems with nixtamalization that are associated with the quality of food preparations. This may be because not all associate poor nixtamalization with poor quality characteristics in their food. The women who do manage to relate the technique to the properties say that overcooking of the nixtamal during the nixtamalization, or an incomplete cooling of the nixtamal after boiling, will produce sticky masas that produces a poor texture in tortillas and tostadas.

Once the pericarp can be removed from the kernel, the nixtamal is left to rest for a variable amount of time. In the Altos and Comiteca regions, the nixtamal is usually prepared in the afternoon and left to soak overnight. In Metropolitana, the common practice is to perform the nixtamal in the morning and steep it for no more than 1 h (Table 2). The women stated that if they soak the nixtamal for longer the masa acquires an acidic aroma and flavor, possibly related to the much warmer climate in this region.

Once the nixtamal has been soaked, it is washed and rinsed with clean water two or three times to remove lime residue, and the kernels are rubbed to remove the skin. The first residue of lime water in which the nixtamal is soaked is known as nejayote. The washed nixtamal is ground between two grooved stones in electric mills to obtain the masa, now known as masa, or it is milled between two grooved metal plates in manual mills.

Women who make pozol in the Metropolitana region stated that they perform the same nixtamalization process, but the nixtamal is coarsely ground. In the Altos region, women mentioned that to make atoles or tamales it is necessary to cook the nixtamal for a longer time.

Nixtamalization with "double boiling" for tostadas

In the Altos region, most the of tostada producers (85%) use the technique known as double boiling for the nixtamal, while less than a third (29%) in Comiteca and no one in the Metropolitana regions practice this procedure. Women associate this technique with softer tostadas, and its origin is uncertain. Apparently, it was unknown before they became producers for the market. In this technique, the nixtamal is first prepared in the conventional way: boiled in lime water, soaked and rinsed. After washing, they boil the nixtamal again in clean water, without lime, until the kernel bursts. This boiling requires a long period of time. Thus, it is common that the second boiling takes place during the night, for which they ensure there is sufficient wood in the stove. In the first boiling of the nixtamal, the kernels are still intact; if the boiling is too prolonged, some could burst, and the lime water would penetrate the

Table 2 Characteristics of the races and maize processing in the study regions

Maize	Region		
	Metropolitana	Comiteca	Altos
Most common race	Tuxpeño	Comiteco	Oloton
Other races available or known	Olotillo	Oloton and Tuxpeño	Tuxpeño
Favorite maize colors	Yellow	Yellow	White and yellow
Boiling time common nixtamal for tortilla, range (min)	35–65	60–85	45–110
Preferred race for tortilla	Tuxpeño	Comiteco	Oloton
Time steeping for nixtamal, range (h)	1	12–16	12–16
Double boiling for the preparing tostadas, range (min)	Not practiced	70–90	80–270
Preferred race for tostadas	Tuxpeño	Comiteco	Tuxpeño
Women that practice double boiling for tostadas (%)	Not practiced	29	85

grain, imparting an unpleasant flavor to the tortilla or tostada.

The next morning the burst grains are rinsed and milled to obtain the masa. Some women described two stages of bursting the kernel: one with the kernel slightly burst, or starting to burst, and the other as "completely" burst (Fig. 3). The masa for the doubled-boiled nixtamal is described as fluffier than the common nixtamal and sticky, which is not a characteristic of common nixtamal. Thus, double-boiled nixtamal is more difficult to work with, but the softer tostada that is produced has a larger demand.

In the Metropolitana region, double boiling is not practiced for tostadas but several women that produce pozol for sale practice a similar technique. These women sometimes keep washed nixtamal without grinding it for one day, after which they boil it again with a small amount of lime until it bursts slightly. They stated that this is needed because their very hot climate spoils the nixtamal quicker, and boiling it again reduces the problem, as does using lime.

Fig. 3 From the Yalumá community in Comitán in the Comiteca region, the yellow maize nixtamal from the Comiteco race that has been double-boiled until the grain looks "burst."

Maize race, kernel hardness and grain color

The three maize races can be found in white and yellow grains. Oloton and Comiteco can be also found in blue/purple and red shades, although the latter are very scarce. The women interviewed in the three regions stated that they prefer their local maize race of yellow grain for household consumption and deemed that these offer a better appearance, flavor and consistency to food. They also indicate that it is easier to wash the nixtamal for yellow maize; thus, they use less water with this grain color. When washing the nixtamal, the white maize requires two or more rinses in water so that the yellow pigmentation caused by the lime does not prevail in tortillas, while a yellow grain nixtamal can be used with only one rinse. In the Altos region, the Tuxpeño are preferred for the tostadas prepared for the market because they make softer tostadas. These maize varieties are not produced in this region, but they are sold in local markets.

All women of the Altos expressed that they recognize the hardness of maize grains (Table 3), though only a third of them do so in both the Comiteca and Metropolitana regions. This difference is possibly related to the fact that in the Altos the Oloton and Tuxpeño maize can be acquired locally or regionally, while the Oloton and Comiteco are not marketed in the Metropolitana region because Tuxpeño is abundant. In the Comiteca region, however, the Comiteco and Tuxpeño are available, although not all women distinguish them. The women of the Altos stated that the Oloton maize is harder than the Tuxpeño.

Only 13.3% of the participants have noticed a difference in the cooking time of the maize from the same race but of different colors. They stated that blue and purple grains cook faster compared with yellow or white.

Preparation of tortillas

Women over 50 years of age reported that there were no tortilla presses before, and they only used their hands to shape the masa into tortillas. In the Metropolitana region, all women use tall wooden stands, known as palmeadores or torteadores (Fig. 4), which they use to form the tortillas. These women use a plastic rectangle

Table 3 Relative frequency (%) of the women's perception of maize grain attributes in three regions of Chiapas

Characteristic	Region			
	Metropolitana	Comiteca	Altos	All
They distinguish grain hardness	30.0	28.6	100.0	60.0
They notice that the Oloton grain is harder than the Tuxpeño	0.0	0.0	100.0	43.3
They recognize the difference in hardness between different colors of the same race	0.0	14.3	23.1	13.3
They detect alterations in nixtamalization	20.0	28.6	38.5	30.0

Fig. 4 Use of palmeadores to flatten the masa and shape the tortillas, in the community of Pacú, in Suchiapa in the Metropolitana region

Fig. 5 Preparation of double-boiled nixtamal masa tostadas in the Campo Santiago community, in Teopisca in the Altos region

that they put on the wooden stand to facilitate the circular movement of the masa, and with the tips of the fingers the masa is spread until a circular tortilla is formed. On the one hand, the contour of the tortilla is shaped, and on the other hand pressure is exercised in such a way that it thins the disk without breaking it.

In the Altos and the Comiteca region, women put the masa between two plastic rectangles in the center of a wooden or metal press and flatten it to shape the tortilla. They press more than once when the tortilla is not even in thickness or shape. The size of the tortilla in the Comiteca and Altos regions is around 12 cm, which is partly determined by the size of the press. In the Metropolitana region, tortillas are larger than 15 cm because it is easy to manually mold more masa on the palmeadores. When the tortillas are flattened, they are placed on a metal griddle known as a comal. Presently, most are made of iron, but a few people still use clay comals. It is very common for women to cover the surface of the griddle with a paste of water with lime or wood ash, so that the tortillas stick less and are easier to turn.

Tortillas are baked similarly in these regions and consist of three cooking phases. First, the tortillas are placed on the comal at about 250 °C and given about 20 s to seal the face ("cara") or the front side of the tortilla. Tortillas are then turned over and cooked for a longer time: 50 to 90 s, to form the back ("espalda") of the tortilla. Tortillas are turned again to the face and cooked for an additional 20 to 40 s until the formation of a puffed or inflated tortilla, generated by water vapor trapped between the face and the back, creates a thin layer in the face.

Preparation of tostadas

When tostadas are made, the women emphasized that they are not prepared in the same way as tortillas. Instead of the three phases described above, the tostadas are done without flipping the tortilla in one cooking phase. The tortilla is left on the comal until it becomes dehydrated, which is determined when the size shrinks, and the surface appears cooked. Done in this way, the inflation is avoided, and a smooth texture is obtained on both surfaces. Once the tortilla is baked, it is dehydrated by toasting it on both sides by placing it on a perpendicular surface close to the fire (Fig. 5), so the infrared heat of the stove dries and toasts the tortilla, giving a brittle tan appearance. Some women use a grilling basket to hold the tortillas flat during the drying.

The tostadas of the three regions show variations. In the Metropolitana region, women use the same nixtamal prepared for tortillas; none of them practiced or knew of double-boiling nixtamal. To prepare tostadas, they prefer to fry the usual tortillas but make them smaller. These tostadas are sturdy, even tough and crisp. In Comiteca and the Altos, tostadas are made mostly with double-boiled nixtamal masa by all women producing them for sale.

Tostadas prepared with the just burst nixtamal are sturdier and less fragile, while the ones with the completely burst nixtamal are more fragile and easier to chew. Some women described that tostadas with slightly burst kernels are better for frying because they absorb less oil. In addition, those with completely burst kernels are the most fragile and better for dry roasting in the oven or comal; these seem to absorb more oil if fried.

Conclusions

Our study of nixtamalization in Chiapas suggests that there are sufficient variations in the process to warrant further research. Nixtamalization is a simple process that can be customized to maize types, environmental conditions and preparations. Despite the simplicity of nixtamalization, making high quality tortillas or tostadas

encompasses specific modifications that women have developed empirically.

We found that the length of the nixtamal 's boiling and steeping times vary from just more than 30 min to almost 2 h. Apparently, this is associated with grain type and with a warmer climate but also with the temperature at which water boils in the regions studied. In lower elevations with warmer environments, women boil the nixtamal for less time and do a short 1-h steeping, the later associated with the much quicker fermentation and decomposition processes that produce off-flavors in this climate. It is believed that the steeping creates conditions for gelatinization, but women from Metropolitana did not comment that their masa had any problem with the short steeping. In the Comiteca and Altos regions, with cooler climates in the mid-elevations and the highlands, maize is steeped overnight without problems with off flavors.

In the Altos region, women have also developed a particular process for the preparation of tostadas known as double boiling. With this technique, crunchier and softer tostadas are produced. Apparently, this was not transmitted from the women's mothers and was developed locally for sale.

All women perceive that nixtamalization and steeping times are related to a good quality tortilla. Women who are engaged in preparing these for sale state that the excessive use of lime, the overcooking of the nixtamal, or an excessive steeping time in a warm climate all produce poor quality tortillas and tostadas.

In the three regions, women identified and stated that they prefer their local maize types when making tortillas for their families because they say these were more satisfying and tasted better, but they also use other maize varieties if available commercially in their regions. In these regions, there is a preference for yellow grain varieties, although in the Altos the white grain of lowland varieties is favored for tostadas intended for sale.

Only the women of the Altos have sufficient experience with local maize and maize introduced from warmer regions; thus, they were the only group that expressed that the hardest grains require more time to nixtamalize.

We did not find the specific transmission of knowledge of the nixtamalization process, maybe because women mention that they learn the technique by watching other persons do it and that the essential aspect is to recognize the consistency of the nixtamal when it is ready to withdraw from the heat. In all cases, women learned indirectly from their family by being in the environment where tortillas are made. In all cases, only women are involved in nixtamal production and tortilla and tostada making. This contrasts with tortilla and tostada production in Mexican cities, where men operate the automatic machinery used in industrial-style production [42]. Industrial-style tortillas and tostadas are not considered ideal as a culinary product in Mexican society, while the artisanal ones described in this article are deemed the archetype of high quality [33, 43, 44].

Nixtamalization is a flexible process that can be adjusted for different maize types and food preparations. The women in Chiapas, who produce for the market, have developed modifications for high-quality foods. Mexican culinary culture is centered on maize products, and therefore, these innovations in nixtamalization are fundamental for this dynamic and exuberant cuisine with worldwide recognition.

This study demonstrates the enduring importance of native corn nixtamalization in regional and local diets. Future studies on other native races of Mexico can be carried out to assess whether these changes in nixtamalization are due to the structural properties of the grain or there are other important variables to consider.

Acknowledgements
We want to thank all the women participating in this study for their collaboration and support.

Authors' contributions
All authors designed the research, analyzed the data and read the manuscript. GPP and HP wrote the manuscript, and GPP performed the fieldwork. EIJEL and JDFC helped to correct the manuscript.

Funding
The first author's doctorate studies were funded by PRODEP-SEP. Fieldwork was supported in part by the "Fondo de Investigación Científica y Desarrollo Tecnológico de El Colegio de la Frontera Sur (FID 784)."

Availability of data and materials
Data are available from the first author upon request.

Declarations

Competing interests
The authors declare that they have no conflicts or competing interests.

Author details
[1]El Colegio de la Frontera Sur (ECOSUR), Unidad San Cristóbal de las Casas, Carretera Panamericana y Periférico Sur S/N, María Auxiliadora, San Cristóbal de las Casas, 29290 Chiapas, CP, Mexico. [2]Universidad de Ciencias y Artes de Chiapas (UNICACH), Ciudad Universitaria, , Libramiento Norte Poniente 1150, Col. Lajas Maciel, Tuxtla Gutiérrez, 29039 Chiapas, CP, Mexico. [3]Centro de Investigación y de Estudios Avanzados del IPN (CINVESTAV), Unidad Querétaro, Libramiento Norponiente 2000, Fraccionamiento Real de Juriquilla, Querétaro, 76230 Querétaro, CP, Mexico.

Received: 17 May 2021 Accepted: 30 December 2021
Published online: 15 January 2022

References

1. Echeverría ME, Arroyo LE. Recetario del maíz. CONACULTA, edit. Mexico: Consejo Nacional para la Cultura y las Artes; 1982.
2. Juárez López JL. Nacionalismo culinario: Hacia una historia de la cocina mexicana en el siglo XX. Escuela Nacional de Antropologia e Historia; 2004.

3. Fernández Suárez R, Morales Chávez LA, Gálvez Mariscal A. Importancia de los maíces nativos de México en la dieta nacional. Una revisión indispensable. Rev Fitotec Mex.. 2013;36(SUPPL.3):275–83.
4. Sanchez JJ, Goodman MM, Stuber CW. Isozymatic and morphological diversity in the races of maize of Mexico. Econ Bot. 2000;54(1):43–59.
5. Ron J, Sanchez JJ, Jimenez AA, Carrera JA, J.G. M, Al. E. Maíces nativos del Occidente de México 1: colectas 2004. Scientia-CUCBA. 2006;8:1–139.
6. Bellon MR. The dynamics of crop infraspecific diversity: A conceptual framework at the farmer level 1.La Dinámica de la Diversidad Infraespecífica: Un Marco Conceptual a Nivel del Agricultor. Econ Bot. 1996;50(1):26–39. https://doi.org/10.1007/bf02862110.
7. Oseguera-Parra D, Ortega-Paczka R. Gente de maíz. Historia y diversidad en la cocina mexicana del maíz. In: López-Moreno I, Vizcarra-Bordi I, editors. El maíz nativo en México Una aproximación crítica desde los estudios rurales. UAM Unidad Lerma/División de Ciencias Sociales y Humanidades. Juan Pablos Edition; 2016. p. 113–36.
8. Serna-Saldivar SO. History of corn and wheat tortillas. In: Rooney LW, Serna-Saldívar SO, editors. Wheat flour and corn products. AACC International: Elsevier Ltd.; 2015. p. 1–28.
9. UNESCO. Traditional Mexican cuisine - ancestral, ongoing community culture, the Michoacán paradigm: United Nations Educational, Scientific and Cultural Organization. 2010. https://ich.unesco.org/en/RL/traditional-mexican-cuisine-ancestral-on-going-community-culture-the-michoacan-paradigm-00400. Accessed 14 Oct 2021.
10. Morton PE. Tortillas: a cultural history. 1st ed. Albuquerque: University of New Mexico Press; 2014.
11. Zizumbo VD, Colunga GP. El uso de las cenizas como posible precursor de la nixtamalización en el oeste de Mesoamérica. Rev Geogr Agrícola. 2016;57:7–18.
12. Cárdenas Marcelo AL, Vizcarra Bordi I, Espinoza-Ortega A, Espinosa Calderón A. Tortillas artesanales mazahuas y biodiversidad del maíz nativo . Reflexiones desde el ecofeminismo de la subsistencia Artisanal Mazahua Tortillas and Native Maize Biodiversity, Reflexion from the Ecofeminism of Subsistence. Soc y Ambient. 2019;7(19):265–91.
13. Ortega TO, García VV, Flores D, Felipe J, Espinoza N. Agrobiodiversidad, género y soberanía alimentaria en Tlaxiaco, Oaxaca. Rev Mex Ciencias Agrícolas Esp. 2017;18:3673–82.
14. Katz SH, Hediger ML, Valleroy LA. Traditional maize processing techniques in the new world. Science. 1974;184(4138):765–73.
15. Serna-Saldívar SO, Gutiérrez-Uribe JA, Mora-Rochin S, García-Lara S. Nutraceutical potential of native maize and changes during traditional and extrusion processing. Rev Fictotecnia Mex. 2013;36:295–304.
16. Gaytán-Martínez M, Figueroa-Cárdenas JD, Reyes-Vega ML, Morales-Sánchez E, Rincón-Sánchez F. Maize landraces selection for industrial end-use based on their added value. Rev Fitotec Mex. 2013;36:339–436.
17. Mauricio Sánchez R, Figueroa Cárdenas J de D, Taba S, Reyes Vega M de la L, Rincón Sánchez F, Mendoza Galván A. Caracterización de accesiones de maíz por calidad de grano y tortilla. Rev Fitotec Mex. 2004;27:213–22.
18. Palacios-Fonseca AJ, Vazquez-Ramos C, Rodríguez-García ME. Physicochemical characterizing of industrial and traditional nixtamalized corn flours. J Food Eng. 2009;93:45–51.
19. Vázquez-Carrillo MG, Rojas-Martínez I, Santiago-Ramos D, Arellano-Vázquez JL, Espinosa-Calderón A, García-Pérez M, et al. Stability analysis of yield and grain quality traits for the nixtamalization process of maize genotypes cultivated in the central high valleys of Mexico. Crop Sci. 2016;56(6):3090–9.
20. Santiago-Ramos D, de Figueroa-Cárdenas JD, Mariscal-Moreno RM, Escalante-Aburto A, Ponce-García N, Véles-Medina JJ. Physical and chemical changes undergone by pericarp and endosperm during corn nixtamalization—a review. J Cereal Sci. 2018;81:108–17.
21. Wacher C. Nixtamalization. A Mesoamerican technology to process maize at small-scale with great potential for improving the nutritional quality of maize based foods the nutritional quality of maize based foods. In: Food-based approaches for a healthy nutrition. 2003. p. 735–44.
22. Mondragón M, Bello-Pérez LA, Agama-Acevedo E, Betancur-Ancona D, Peña JL. Effect of cooking time, steeping and lime concentration on starch gelatinization of corn during nixtamalization. Starch/Staerke. 2004;56:248–53.
23. Trejo-Gonzalez A, Feria-Morales A, Wild-Altamirano C. The role of lime in the alkaline treatment of corn for tortilla preparation. Modif Proteins Food, Nutr Pharmacol Asp (Advances Chem Ser 198). 1982;245–63.
24. Pappa MR, de Palomo PP, Bressani R. Effect of lime and wood ash on the nixtamalization of maize and tortilla chemical and nutritional characteristics. Plant Foods Hum Nutr. 2010;65:130–5.
25. Castillo VKC, Ochoa MLA, Figueroa CJD, Delgado LE, Gallegos IJA, Morales CJ. Efecto de la concentración de hidróxido de calcio y tiempo de cocción del grano de maíz (*Zea mays* L.) nixtamalizado, sobre las características fisicoquímicas y reológicas del nixtamal. Arch Latinoam Nutr. 2009;59:425–32.
26. Quintanar Guzmán A, Jaramillo Flores ME, Mora Escobedo R, Chel Guerrero L, Solorza Feria J. Changes on the structure, consistency, physicochemical and viscoelastic properties of corn (*Zea mays* sp.) under different nixtamalization conditions. Carbohydr Polym. 2009;78(4):908–16.
27. González-Amaro RM, Figueroa-Cardenas JDD, Perales H, Velés-Medina JJ. Physicochemical and nutritional properties of different maize races on toasted tortillas. Cereal Chem. 2017;94(3):451–7.
28. Cruz-Vazquez C, Villanueva-Carvajal A, Estrada-Campuzano G, Dominguez-Lopez A. Tamales texture properties as a function of corn endosperm type. Int J Gastron Food Sci. 2019;16(April): 100153. https://doi.org/10.1016/j.ijgfs.2019.100153.
29. Roque-Maciel L, Arámbula-Villa G, López-Espíndola M, Ortiz-Laurel H, Carballo-Carballo A, Herrera-Corredor JA. Nixtamalización de cinco variedades de maíz con diferente dureza de grano: Impacto en consumo de combustible y cambios fisicoquímicos. Agrociencia. 2016;50(6):727–45.
30. Méndez-Montealvo G, Trejo-Espino JL, Paredes-López O, Bello-Pérez LA. Physicochemical and morphological characteristics of nixtamalized maize starch. Starch/Staerke. 2007;59(6):277–83.
31. Narváez-González ED, Figueroa-Cárdenas JDD, Taba S, Rincón SF. Kernel microstructure of Latin American races of maize and their thermal and rheological properties. Cereal Chem. 2006;83(6):605–10.
32. Staller JE. Maize cobs and cultures: history of *Zea mays* L. Berlin: Springer; 2010. p. 266.
33. Palacios-Pola G, Perales Rivera H, Figueroa-Cárdenas J de D, Hernández Estrada ZJ. Changes in the physical, chemical, and sensory properties from three native corn landraces from Chiapas using two nixtamalization times. Vol. 25, Int J Gastron Food Sci. 2021.
34. Díaz Hernández BM, Silva Pérez L del C, Francisca VL, Perales Rivera HR. Más allá de la milpa. Relatos de mujeres que amasan la vida. 1st Edition. ECOSUR, ed. San Cristóbal de las Casas; 2018. 57 p.
35. Perales RH, Hernández-Casillas JM. Diversidad del maíz en Chiapas. In: González-Espinosa M, Ramírez-Marcial N, Ruíz-Montoya L, editors. Diversidad Biológica en Chiapas. México: El Colegio de la Frontera Sur; 2005. p. 337–55.
36. Brush SB, Perales HR. A maize landscape: ethnicity and agro-biodiversity in Chiapas Mexico. Agric Ecosyst Environ. 2007;121:211–21.
37. Perales H, Golicher D. Mapping the diversity of maize races in Mexico. PLoS ONE. 2014;9(12):1–20.
38. Wellhausen EJ, Roberts LM, Hernández X. E. Razas de Maíz en México, su origen, características y distribución. 1st Edition. Ciudad de México: Aldina Rosell y Sordo Noriega, S. de R.L.; 1951. 239 p.
39. Narváez-González ED, Figueroa-Cárdenas JDD, Taba S, Castaño Tostado E, Martínez Peniche RÁ, Rincón SF. Relationships between the microstructure, physical features, and chemical composition of different maize accessions from Latin America. Cereal Chem. 2006;83:595–604.
40. UNESCO. Nsima, culinary tradition of Malawi. United Nations Educational, Scientific and Cultural Organization. 2017. https://ich.unesco.org/en/RL/nsima-culinary-tradition-of-malawi-01292?RL=01292%0A. Accessed 27 Sep 2021.
41. Vizcarra Bordi I, Marín Guadarrama N. Las niñas a la casa y los niños a la milpa: la construcción social de la infancia mazahua. Convergencia. 2006;13(ISSN 1405–1435):39–67.
42. Torres F, Moreno E, Chong I, Quintanilla J, edits. La industria de la masa y la tortilla. Desarrollo y Tecnología. First Ed. Taxco, Guerrero: Universidad Nacional Autónoma de México; 1995.

43. Vázquez-Carrillo MG, Guzmán-Báez L, Andrés-Garcia JL, Márquez-Sánchez F, Castillo-Merino J. Calidad de grano y tortillas de maíces criollos y sus retrocruzas. Rev Fitotec Mex. 2003;26:231–8.
44. Rangel Meza E, Muñoz Orozco A, Vazquez Carrillo G, Cuevas Sanchez J, Merino Castillo J, Miranda CS. Alkaline cooking, preparation and quality of corn tortilla. Agrociencia. 2004;38:53–61.
45. INEGI. Panorama Sociodemográfico de Chiapas. Censo de Pobración y Vivienda. 2010. https://www.inegi.org.mx/contenidos/productos/prod_serv/contenidos/espanol/bvinegi/productos/censos/poblacion/2010/panora_socio/chis/702825003348.pdf.

Publisher's Note