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The Effects of Food Processing on the Archaeological Visibility of Maize: An Experimental Study of Carbonization of Lime-treated Maize Kernels

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Abstract: *This paper explores the effects of maize processing on the carbonization and preservation of maize kernels in the archaeological record. The shift to processing maize with lime (known as hominy production in the Eastern Woodlands and nixtamalization in Mesoamerica) in ancient times had the effect of making maize more nutritious through increasing the availability of calcium, niacin, dietary fiber, and essential amino acids. Less understood is how this process of cooking maize in a lime solution affects the archaeological preservation of maize; if there is a clear difference in the archaeological signature of maize remains that are and are not processed this way, then this process may be identifiable in the archaeological record. To this end, an experiment was constructed analyzing the variation in size between dried and alkali processed maize kernels before and after carbonization. Results indicate that alkali processed maize kernels are less likely to fragment during carbonization.*

Key Words: maize processing, nixtamalization, Mesoamerica, paleoethnobotany, carbonization

Introduction

The effects of ancient processing on the archaeological visibility and recovery of maize is important for reconstructing past subsistence practices in the New World. Because maize was a prominent cultivar in the Americas, it is important to determine the varieties people grew and the processing methods employed. Previous studies by Goette et al. (1994), King (1987), and Pearsall (1980) addressed this issue through recreating ancient processing techniques (e.g. boiling, sprouting, and parching) to see how these methods affected preservation in the archaeological record. However, these studies were broad in scope and used charring techniques that provided inconclusive results. Because of severe distortion to kernel morphology, measurements of kernel shape and size were inaccurate and did not provide reliable results regarding how processing affects carbonization and preservation. As a result, past studies were unable to make direct comparisons between modern carbonized kernels and archaeological carbonized kernels to determine the processing techniques used. This study compares archaeological and modern samples to determine how alkali processing alters phenotypes of New World maize varieties, as well as to establish parameters for identifying alkali processed kernels employing a charring technique that allows for complete carbonization of the kernel, without damage. Hence, this research adds to the body of data on ancient maize processing techniques by specifically exploring how alkali processing affects the archaeological preservation of different maize varieties (Martinez-Bustos et al. 2001). The process of alkali cooking, known as hominy production in the Eastern Woodlands and nixtamalization in Mesoamerica, was widely used by societies living throughout Mesoamerica and North America. I first address the origins and use of alkali processing in the Americas. This is followed by a brief consideration of quantification methods and lab procedures, which is followed by results of the experiments and discussion of their implications for maize-variety identification, processing method identification, and general importance in New World archaeology.

Alkali Processing of Maize

The purpose of cooking maize with an alkali substance is to lengthen its storage life, to increase its nutritional content by changing the chemical and physical composition of the kernels, and to facilitate the removal of the pericarp (Martínez-Bustos et al. 2001). Unprocessed, maize is deficient in niacin and the essential amino acids lysine and tryptophan; however, alkali processing enhances the potency of these nutrients (King 1987). The traditional process involves the use of alkali cooking, steeping, and washing to remove maize skin from the kernels before consumption or storage (Martinez-Bustos et al. 2001). Martinez-Bustos et al. (2001) state that cooking with an alkali substance (e.g., wood ash) allows for increased water uptake, thus resulting in kernel expansion. The amount of water uptake depends heavily on the maize genotype and processing conditions, such as water temperature and time soaked and cooked (Martinez-Bustos et al. 2001). However, depending on how the maize variety reacts to the process, alkali-processed maize kernels could be differentially preserved through carbonization compared to unprocessed carbonized kernels.

Four varieties of maize representing modern descendants of archaeological varieties—also known as heirloom varieties—were selected for experimentation to determine how different maize varieties are affected by alkali processing. It is impossible to obtain modern maize with the exact genetic make-up of their archaeological ancestors, due to evolution; thus, the kernels were acquired from Seeds of Change (www.seedsofchange.com) based on geographic origin and cultural connections (i.e. the historical significance of the heirloom variety in a given region). The four types selected were Oaxacan Green, Anasazi Flour, Hopi Pink, and Hickory King. Both the Oaxacan Green (originating from the Zapotec Indians in Southern Mexico and green in color) and the Hickory King (originating in the southeast United States and yellow in color) are dent varieties. Dent maize is characterized by a starchy endosperm in the middle, extending towards the top of the kernel that is surrounded by a corneous endosperm along the sides (Sturtevant 1898). Hickory King is known to be used for hominy in the southeastern United States (www.victoryseeds.com). In contrast, Anasazi Flour (a multi-colored maize) and Hopi Pink are soft-flour varieties from the southwestern United States. The flour varieties are considered soft due to the absence of corneous endosperms and the lack of indentation (Sturtevant 1898).

It is difficult to make a direct comparison between archaeological specimens and contemporary races of maize even when the evolutionary relationships are well understood because maize is constantly evolving due to human selection (Benz 1994). Therefore, there is little information available that allows archaeologists to make comparisons of maize kernels over large areas and through time. Nevertheless, by studying farmer or heirloom varieties, for which change is slower compared to many other varieties, archaeologists can create a statistical method of analysis to demonstrate correlations of size between modern and ancient varieties (Blake and Cutler 2001). As most archaeological maize is carbonized, if the effects of alkali processing can be determined, it may be possible to better characterize archaeological varieties. According to King (1987), there are five kernel measurements that can be used to determine variety; these include angle, length, width, thickness, and distance from base to widest part of the kernel. Several studies (e.g., Pearsall 1980; Goette et al. 1994; Blake and Cutler 2001) have attempted to determine variety using kernel angle to estimate the number of rows on each cob. However, this measurement does not take into account distortion and shrinkage due to charring or processing. Blake and Cutler (2001) suggest that up to 40% distortion in characteristics can occur during the carbonization process, which alters the kernel angle. Thus, kernel angle is not an accurate tool for determining varieties and the most accurate results are based on determining pre- and post-carbonization length, width, and thickness (King 1987). Given these challenges, the purpose of this experimental study is to: (1) determine the best way to identify alkali processing of maize in the archaeobotanical record and (2) understand how the alkali process affects different maize varieties.

Previous Research

As suggested by King (1987), processing method plays a role in determining charred kernel shape. Understanding the differences in carbonized kernel morphology is essential for characterizing different varieties. In terms of alkali processing, I draw on several previous studies. The first study, conducted by Goette et al. (1994), examined three different races of Andean maize using techniques of toasting, sprouting, and boiling. The second study, based in North America and conducted by Francis King (1987), describes how alkali processing alters the kernel shape. Both experiments conclude that most maize recovered from archaeological sites was likely boiled with wood ash (Goette et al. 1994; King 1987). Charred kernels with endosperm extrusion (when the endosperm expands greatly, causing a fragile and extreme distortion to the kernel) are unlikely to survive in the archaeobotanical record. Therefore, maize kernels processed by sprouting or toasting, which have high percentages of extrusion, are unlikely to survive, especially compared to boiled kernels, which only have an extrusion percentage of 10-15% (Goette et al. 1994). Goette et al.'s (1994) findings support ethnographic data suggesting the process of boiling maize with wood ash was a widespread practice throughout North and South America. Because Goette et al. (1994) focused on only three varieties indigenous to Peru, it is important to expand experimentation to other varieties so as to provide an accurate representation of processing and preservation throughout the New World (Goette et al. 1994). Hence, further knowledge of how alkali processed kernels react to carbonization will help archaeologists determine the processing method used and the number of different varieties at a given site based on morphological characterization (Goette et al. 1994).

Because most recovered archaeobotanical remains are charred, it is difficult to distinguish maize varieties and processing techniques based on morphology alone. Past experiments used charring methods in an attempt to recreate archaeological maize and to understand how carbonization affected morphology. Often, these studies provided inconclusive results due to the nature of particular charring methods that left kernels indistinguishable. For example, Cutler and Blake (1973) suggest that kernels carbonized loose (i.e. not on the cob) become too distorted to provide any type of meaningful measurements. However, other scholars indicate that kernels can be charred not on the cob, when packaged tightly together, which avoids extreme distortion to the kernel shape (Goette et al. 1994; King 1987). Nevertheless, because previous charring experiments were conducted under conditions of too rapid or too high heat, the morphology of the charred kernels were too distorted and provided inaccurate and unreliable measurements for determining kernel size and shape (King 1987; Pearsall 1990). In past experiments parching techniques were used to obtain measurable results (Goette et al. 1994; King 1987; Pearsall 1990). However, parching likely does not provide analogical realism as it does not cause the same changes in morphology or the representation of archaeological kernels that is caused by charring. For the current experiment it was important to develop and use a method of charring that would preserve the features (length, width, and thickness) and shape of the kernels so as to make them comparable to archaeological specimens.

Materials and Methods

To determine how alkali processing and carbonization affects the morphology of kernels, it was necessary to perform a laboratory experiment to determine how these processes affect kernels of the four selected varieties of maize. Based on experimental design from Goette et al. (1994) and King (1987), an experiment was constructed to analyze size variability among maize kernels that were a) dried, b) alkali processed, c) dried and carbonized, and d) alkali processed and carbonized. Sample size varied from 40-45 kernels per variety.

Initially, each dried kernel was photographed and measured using a stereo-microscope with a camera attachment. I recorded kernel weight, length, width, and thickness, as these are morphological characteristics that relate to reproduction and that are least affected by environmental variability in phenotype (Goodman and Paterniani 1969). The next step involved a 50% random selection of each variety to be processed in an alkali solution. In order to use historically appropriate methods and follow convention of previous alkali processing experiments, ten pounds of uncontaminated oak, maple, and ash wood were burned to produce ash for the alkali solution. Three cups of the hardwood ash were boiled in six quarts of water for one hour to achieve a pH of 10 (Goette et al. 1994). The water was then sieved and divided between four pots, one for each maize variety, and the maize was soaked for fourteen hours (Martinez-Bustos et al. 2001). After soaking, the maize was cooked at 85° Celsius for one hour, at which point the pericarps began to loosen. The kernels were then rinsed under running water and rubbed together to remove seed coats and points of attachment. After drying, the alkali-processed kernels were re-measured.

The next step was carbonization. Because research by Blake and Cutler (1973) suggests that kernels carbonized loose will cause distortion, kernels were placed in tin-foil packets before carbonization. In total there were eight tin-foil packets that were carbonized—two for each variety with one containing the unprocessed kernels and the other containing the alkali-processed kernels. The kernels were cooked in a muffle furnace at 180-190ºC, conditions that represent a low-burning fire, for one hour and then were removed from the furnace to cool for three minutes (Werts and Jahren 2007). They were then cooked for one more hour at which point smoking ceased, which is indicative of complete charring. The purpose of the double cooking method was to mitigate issues that previous studies experienced—these include carbonizing kernels in too high of heat or too rapidly. Because this research is experimental, temperature and cooking time were controlled. However, archaeological kernels would not have been exposed to consistent heat, as fire temperatures and surrounding soil temperatures vary (Werts and Jahren 2007). During the initial phase of the carbonization process, the unprocessed kernels cracked, at an average rate of one to two pops per five minute period, exhibiting splitting and swelling. After one hour, these unprocessed kernels became surrounded by a foamy black matrix. When carbonization was complete, all kernels were re-measured using the same methods as prior to processing. Dependent t-tests are used to assess differences in shrinkage among dried, alkali-processed, and carbonized kernels.

Results

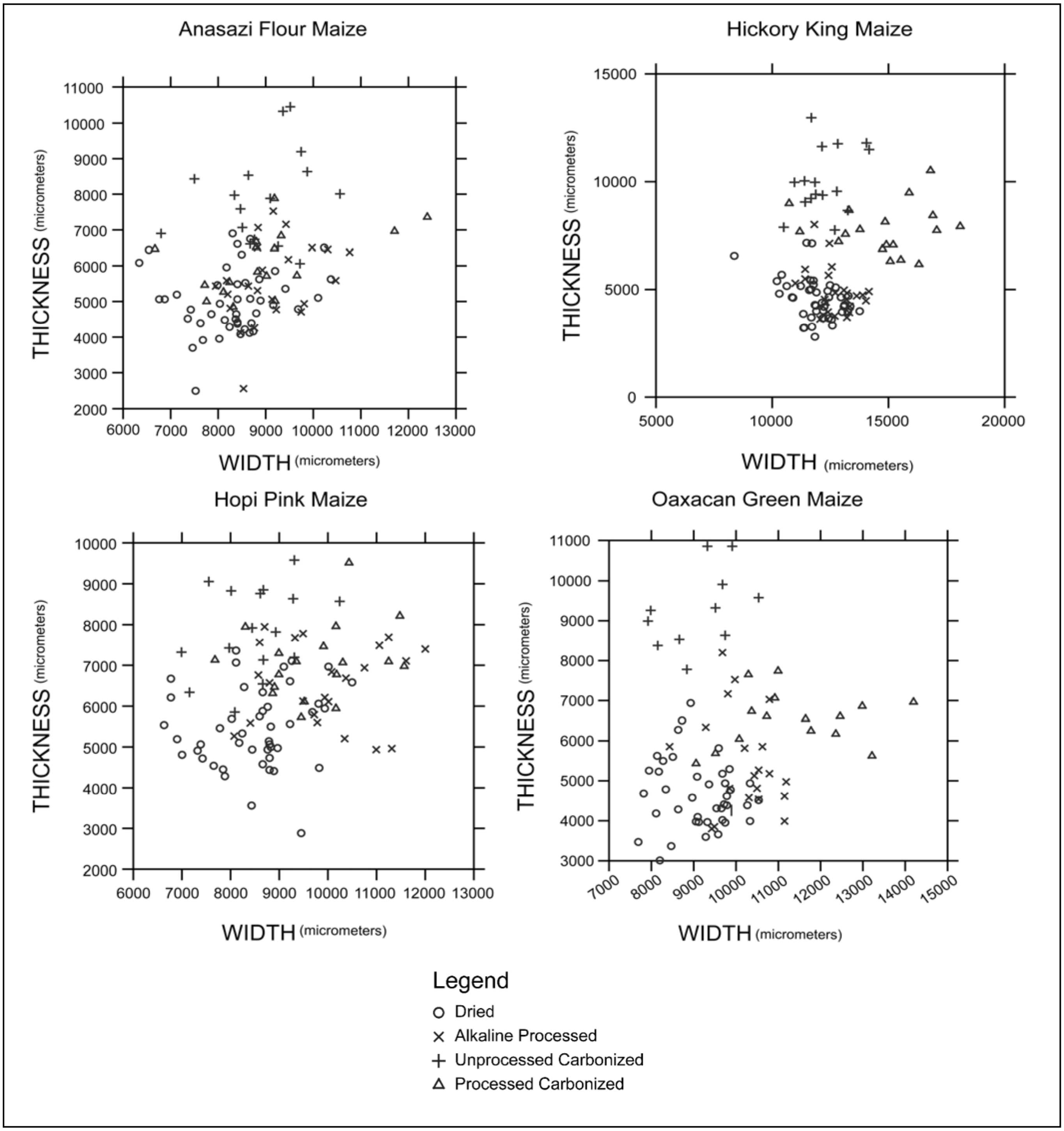
By using a controlled charring environment, I was able to carbonize specimens that exhibit similar morphologies to archaeological specimens (including those found at sites in the Midwestern United States[1]), which allows insights into how processing affects maize kernel taphonomy. The metric dimensions of the carbonized alkali-processed kernels were greater than those of non-alkali-processed kernels. There are substantial differences between the (a) dried, (b) alkali processed, (c) unprocessed carbonized, and (d) alkali processed carbonized kernels. There were clear differences in thickness and width amongst the varieties. The increase in thickness between dried (a) and alkali-processed-carbonized (d) ranged from 21.64% for Anasazi Flour to 71.38% for Hickory King. In addition, the lengths of the kernels decreased in size after alkali processing and again after carbonization; this decrease ranged from 3.09% for Hickory King to 22.05% for Hopi Pink. Goette et al. (1994) report similar results, indicating that the decrease in moisture causes vertical contraction of kernels, whereas increasing internal pressure causes horizontal expansion.

These differences are best demonstrated visually with scatterplots. Note that the majority of alkali-processed-carbonized kernels show an increase in width and thickness (Figure 1), when compared to the (non-carbonized) dried and alkali-processed kernels. In addition, the unprocessed-carbonized kernels show an increase in thickness, but not width, which indicates that carbonization is a contributing factor to increased thickness. It is thus logical to conclude that the increase in internal pressure that occurs during carbonization forces the kernels to expand in thickness; however, because of decreased moisture content in the absence of alkali processing, other factors, such as length and width, appear not to increase under carbonization alone. Therefore, the magnitude of width expansion is likely dependent upon cooking method. This interpretation is supported by visual inspection of Figure 2, which plots length by width for all four varieties under different experimental conditions.

By examining the scatterplots, it is evident that the alkali-processed and the alkali-processed-carbonized kernels exhibit the greatest shift in width when compared to the dried maize and unprocessed-carbonized kernels. The majority of the alkali-processed Hopi Pink kernels and Anasazi Flour Kernels show the largest increase in width after processing, and exhibit a slight decrease in width with carbonization. The fact that the alkali-processed kernels exhibit greater width than the alkali-processed-carbonized kernels indicates a decrease in kernel moisture content caused by carbonization. Unless kernels are alkali processed, they should not have significant changes in width.

The use of dependent t-tests allows for statistical analysis of shrinkage in kernel dimensions. A comparison of the dried kernels (a) with the alkali processed kernels (b) was beneficial to determining the impact that alkali processing has on kernel shape. Tests on width measurements between these pairs (for all varieties) yield p-values less than 0.05, indicating significant differences in width—in other words, alkali processing leads to significant kernel swelling along this dimension (Table 1). There is also a significant difference in width between unprocessed carbonized kernels (c) to alkali processed carbonized kernels (d) (p-value < 0.001).

Dependent t-tests were also used to determine statistical differences in thickness (Table 1). For all varieties, it was determined that thickness increases with carbonization. Additionally, unprocessed carbonized kernels (c) and alkali processed carbonized kernels (d) were compared in order to determine if the measurement of thickness could be used to determine the different processing methods in archaeological kernels. Dependent t-tests demonstrate that the differences are significant; thus, for archaeological specimens, comparisons of the width and the thickness of kernels, assumed to be the same variety,



Anasazi Flour Maize

Hickory King Maize

Hopi Pink Maize

Oaxacan Green Maize

Figure 1. Results from scatter-plots of width vs. thickness for Anasazi Flour, Hickory King, Hopi Pink, and Oaxacan Green maize kernels.

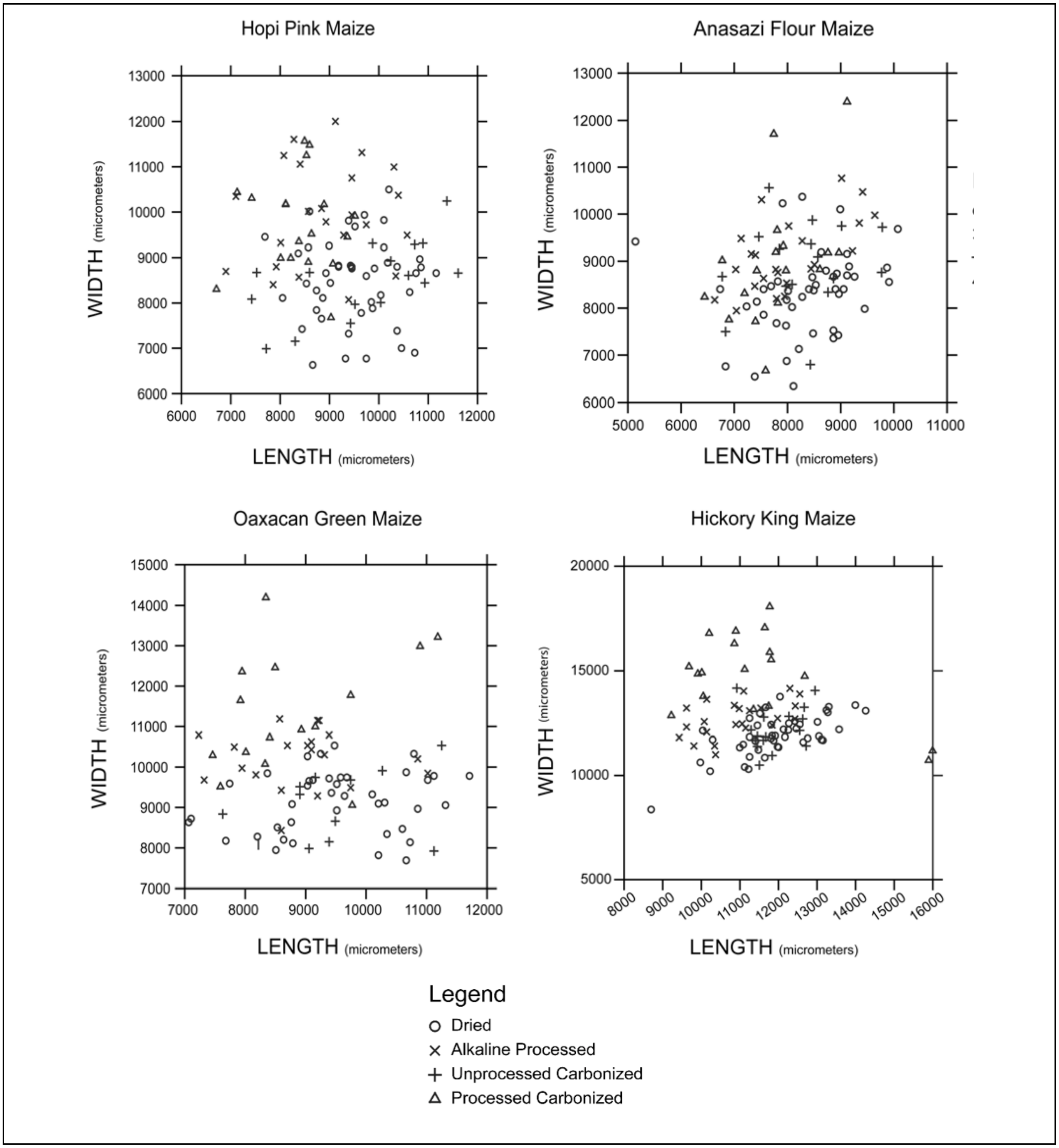


Figure 2. Results from scatter-plot of length vs. width Anasazi Flour, Hickory King, Hopi Pink ,and Oaxacan Green maize kernels.

Table 1. Results of two-sample t-tests with separate variances for Anasazi Flour, Hickory King, Hopi Pink, and Oaxacan Green maize kernels.

Maize Type	Pairs for Kernel Width	t	df	p-value		Pairs for Kernel Thickness	t	df	p-value
Anasazi Flour	A / B	3.855	50.5	0.000*	Anasazi Flour	A / C	8.301	20.4	0.000*
	C / D	0.169	28.3	0.867		C / D	4.723	26.3	0.000*
Hickory King	A / B	3.541	51	0.001*	Hickory King	A / C	13.661	19.5	0.000*
	C / D	4.813	26	0.000*		C / D	4.881	27.8	0.000*
Hopi Pink	A / B	5.377	38.1	0.000*	Hopi Pink	A / C	7.837	24.1	0.000*
	C / D	3.817	31.7	0.001*		C / D	2.195	29.5	0.036*
Oaxacan Green	A / B	5.336	40.4	0.000*	Oaxacan Green	A / C	14.24	14.5	0.000*
	C / D	4.926	23.2	0.000*		C / D	8	16.9	0.000*

Note: A = dried ; B = alkali processed ; C = unprocessed carbonized ; D = alkali processed carbonized ; * indicates statistical significance

can allow researchers to determine whether or not alkali processing occurred before carbonization. Kernels that exhibit increased thickness and width indicate alkali processing and carbonization whereas, kernels that only exhibit increased thickness suggest carbonization alone. Additionally, because data suggest that the widths and thicknesses for each variety fall within certain ranges, researchers could separate kernels into varieties. Specifically, dent varieties of maize display larger width and thickness dimensions than flour varieties. After carbonization, the median width for the alkali processed Anasazi flour kernels was 8826.5 µm and the median width for the alkali processed Hopi Pink was 9713.0 µm. In contrast the processed and carbonized Oaxacan Green dent measured 10994.9 µm and the Hickory King dent measured 1499.36 µm. Results for thickness demonstrate a similar pattern with the median Anasazi Flour and Hopi Pink, measuring 5829.1 µm and 7079.1µm, respectively, while median thickness for Oaxacan Green and Hickory King were 6607.1 µm and 7710.5 µm, respectively. Both measurements indicate that flour varieties will be smaller in size after carbonization than dent varieties.

After experimental carbonization, there was a large phenotypic difference between the kernels that were boiled in the alkali solution and then carbonized compared to those that were only carbonized. The reason for this difference is that the effect of heating on kernels is directly correlated to endosperm composition (King 1994). Because the four varieties were composed mainly of floury endosperms, they were more likely to swell and split due to intense pressure build-up in the early stages of carbonization (King 1994). The unprocessed kernels expanded and split, making them unrecognizable, while the alkali-processed kernels maintained their shape and structure. The majority of Hickory King, Oaxacan Green, Hopi Pink, and Anasazi Flour unprocessed kernels split and became globulated, which indicates that the starches oozed out the pericarp due to internal pressure that produced foamy black matrices. The kernels also became very brittle—a clear indicator that unprocessed kernels are not good candidates for archaeological preservation as they would likely suffer significant mechanical damage, leading to higher rates of fragmentation.

In contrast, the alkali processed kernels appeared very similar to archaeological specimens (e.g., from Myer-Dickson and Roskamp sites located in the Central Illinois River Valley in the midwestern United States). A few of the Oaxacan Green kernels cracked along the exterior, which is likely due to not being soaked long enough in the alkali solution. Nevertheless, all of the kernels were identifiable and durable. It is important to note that unlike some archaeological kernels, the embryos of the kernels used in the experiment stayed attached after carbonization, which is most likely due to the effects of uniform temperature in the controlled carbonization environment. The lack of distortion in the alkali-processed kernels likely relates to the fact that boiling softens the endosperm, thus allowing the kernel to swell without splitting.

Discussion and Conclusion

It is evident from these results that the distinguishing characteristics of carbonized maize are not only based on the genotypic variety but also on the processing mechanisms which the kernels undergo (Goette et al. 1994). Upon carbonization, most of the alkali processed kernels were similar in appearance to kernels recovered at archaeological sites in the midwestern U.S. (Myer-Dickson, Roskamp, Lamb)[i], which do not have embryos and are broad and crescent shaped (King 1994). Therefore, it can be assumed that various Native American groups were using a method of alkali processing, which results in better archaeological preservation of the kernels. However, the use of alkali processing creates a preservation bias at archaeological sites due to the fact that it is primarily alkali processed kernels that remain complete, compared to unprocessed kernels which are more brittle and tend to fragment (King 1994). Because the studies indicate that unprocessed kernels become distorted when carbonized, the probability of finding identifiable unprocessed complete kernels is slim compared to finding kernels that are alkali processed (Goette et al. 1994; King 1994). Additionally, certain varieties, based on endosperm composition, were more likely to be alkali processed than others, and thus, the varieties of recognizable maize found at archaeological sites favor those that underwent alkali processing, which would most likely be dent and flour varieties. Due to the fact that there have not been many studies conducted on alkali processing, further research is needed to determine archaeological varieties that underwent processing. What this study does conclude is that alkali processed kernels, which are not brittle and are less likely to fragment, are more readily found at archaeological sites than unprocessed kernels. Through the use of statistical analysis that examines kernel morphology, researchers will be able to categorize and determine the number of varieties at a site based on measurements of length, width, and thickness.

It is also important to note that there are problems based on developing methods of measurement and of statistical analysis that can be applied to maize varieties from different sample groups. Because of genetic differences, it is difficult to make direct comparisons between the samples created in a laboratory and those formed in the archaeological record (Goette et al. 1994). However, understanding of genealogy and varietal relationships can help mitigate this problem. In addition, because every variety of maize reacts differently to alkali processing and, therefore, the results for one variety will be different than those of another variety, different varieties can be grouped based on statistical differences. Finally, this study focused on flour and dent varieties; we still do not understand how flint, sweet, or popcorn varieties (which have different endosperm compositions) are altered by alkali processing. Nevertheless, this study does provide conclusive evidence that alkali processed kernels, when carbonized, will demonstrate increased widths, increased thickness, and loss of pericarps and points of attachment (indicative of alkali processing). If kernels were not alkali processed, they would not lose their pericarps, and therefore, would have different phenotypic compositions than alkali processed kernels.

Future studies must be conducted in order to determine which archaeological maize samples were alkali processed. The current study demonstrates that there are morphological similarities between modern alkali processed, carbonized kernels and archaeological kernels; however, studies analyzing the chemical composition of archaeological kernels are still needed. It would also be beneficial to conduct burial studies to analyze how modern alkali processed, carbonized varieties, placed underground for an extended period of time, react to environmental pressures. The use of burial studies would allow researchers to determine how local environmental conditions affect composition of the alkali processed kernels to determine if more phenotypic or chemical changes occur.

As suggested by modern ethnographic data, there is a high correlation between societies that cultivate and consume maize and those that use alkali processing (King 1987). Additionally, we know that alkali processing diffused from Mesoamerica to North America, but further research is necessary to understand when diffusion occurred (King 1987). Future studies must also determine when different groups in Mesoamerica and North America first used alkali processing. To do this, analysis of a broader range of maize varieties, including archaeological kernels from different time periods, needs to occur. Nevertheless, this study provides clear evidence of the importance of alkali processing for the preservation of archaeological maize and for the identification of different maize phenotypes. Understanding how alkali processing affects kernel morphology will allow archaeologists to formulate a statistical method for determining processing techniques and maize varieties in the archaeobotanical record.

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Biosketch

Caroline Dezendorf is currently pursuing her Master's Degree in International Studies at the University of Oregon. Her current research focuses on issues of food justice and Latino immigration.

Notes

[1] These samples are currently being analyzed in Dr. Amber VanDerwarker's lab at UC-Santa Barbara.