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TOWARD RECONSTRUCTING ANCIENT MAIZE: EXPERIMENTS IN PROCESSING AND CHARRING

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ABSTRACT.—We report the results of two experiments designed to assess the effects of processing and charring on maize fragments, so as to allow improved interpretation of maize remains recovered from archaeological sites. In the first experiment, kernels of three varieties of modern Andean maize were processed by three methods—toasting, sprouting, and boiling with wood ash—and then charred. The three processing techniques produced diagnostic characteristics that survived charring. It was also found that dimensional changes with charring were greater in processed kernels than unprocessed kernels. In the second experiment, after establishing a set of charring conditions, ears of six varieties of Andean maize were fragmented and the kernels and cupules measured before and after charring to determine the direction, degree, and variability of distortion.

RESUMEN.—Reportamos los resultados de dos experimentos diseñados para evaluar los efectos del procesamiento alimentario y la carbonización de fragmentos de maíz, a fin de permitir una mejor interpretación de los restos de maíz provenientes de sitios arqueológicos. En el primer experimento, se procesaron granos de tres variedades de maíz andino contemporáneo mediante tres métodos: fueron tostados, germinados, o hervidos con ceniza, y todos fueron después carbonizados. Las tres técnicas de procesamiento produjeron características que perduraron después de la carbonización y que pueden servir como diagnóstico. Se encontró también que los cambios de dimensiones ocasionados por la carbonización fueron mayores en granos procesados que en granos no procesados. En el segundo experimento, después de establecer ciertas condiciones de carbonización, se fragmentaron mazorcas de seis variedades de maíz andino y se midieron los granos y las cúpulas antes y después de la carbonización para determinar la dirección, grado y variabilidad de la deformación.

RÉSUMÉ.—Nous reportons les résultats de deux expériences destinées à évaluer les effects d'utilization culinaire et de carbonization sur les fragments de mais, de façon à améliorer l'interprétation des restes de mais provenant de contextes archaéologiques. Dans la première expérience, les graines de trois variétes de mais moderne des Andes ont été grillées, germinées, et bouilliees avec des cendres de bois, puis carbonizées. Ces trois techniques ont produit des charactéristiques diagnostiques qui ont survécu la carbonization. Entre autre, les changements dans les dimensions dus à la carbonization sont plus importants dans les graines préparées que nonpréparées. Dans la deuxième expérience, après avoir établi certaines conditions de carbonization, les épis de six variétés de mais andéens ont été fragmentés et les graines et cupules mesurées avant et après la carbonization, de façon à préciser la direction, le degré et la variabilité des distortions.

INTRODUCTION

Domesticated maize (*Zea mays* subsp. *mays*) achieved perhaps the widest prehistoric distribution of any New World crop, spread by human agency from Mesoamerica north to the boreal forests of Canada and south to Argentina and Chile. In the process the maize ear underwent phenotypic and genotypic variation into a myriad of colors, sizes, shapes, and textures. Hundreds of maize varieties were in use in the Americas at the time of European contact. These varieties, created and maintained by human groups each for its own particular purpose, were cultural artifacts. The recognition of these varietal differences in ancient maize remains recovered from archaeological sites is important for understanding the long and complex interaction between people and maize.

The difficulty inherent in distinguishing maize varieties on the basis of the morphologies of a few specimens (Bird 1970; Bird and Goodman 1978; Goodman and Paterniani 1969; King 1987) is increased by the fact that in many archaeological sites maize is preserved only if it was charred in antiquity. Further, maize ears generally have been fragmented through processing, charring, and other depositional forces into loose kernels, kernel fragments, and cob fragments consisting of the hard cupules that held the kernels. Several researchers (Benz 1994; Bird and Bird 1980; Cutler 1956; Cutler and Blake 1973; Pearsall 1980; Johannessen et al. 1990; King 1987, 1994; Miksicek et al. 1981) have addressed the problem of developing methods of measurement and statistical analysis that can be applied to classifying these charred fragmentary maize remains.

If archaeological maize types are to be reconstructed, it is essential to know how accurately measurements taken on charred fragments reflect the attributes of the original ear. Heating and charring distort the size and shape of kernels and cupules. Also, various types of maize processing undoubtedly changed kernel characteristics. The effects of charring and processing can be assessed by experimental means, and here we report on two experiments toward this end. The results should be understood only as one piece of the complex puzzle of reconstructing ancient maize. The myriad varieties of maize as well as variables in processing and charring conditions make it unwise to use the results as formulas to be applied to every set of archaeological maize fragments.

Several previous researchers have approached this same problem. Cutler (1956) and Cutler and Blake (1973) give the approximate effect of charring on cob parts and on kernels, but it is not clear whether their conclusions are based on observations of archaeological material or on experimental reconstructions. Pearsall (1980) experimented with charring and parching modern maize kernels in order to arrive at an appropriate adjustment to reconstruct the original size and shape of a cache of charred archaeological kernels. However, she was not successful in replicating the condition of the archaeological kernels, which appeared to have little distortion, pericarp splitting, or extrusion of the endosperm. After heating for 1.5 hours in sand over a Bunsen burner, the modern charred kernels were extremely swollen and broken, which Pearsall attributes to too high heat or too rapid heating. Modern kernels that were parched but not charred showed less distortion, and Pearsall estimated that ancient charring produced size increases of 5% in length, 10% in width, and 50% in thickness, percentages midway between the changes in the experimental charred and parched kernels. More recently, King (1987, 1994) has experimented with the effect of different charring regimes, as well as differences with variation in processing techniques (boiling and alkali treatment) and endosperm types. She too was unable to reproduce by experiment the condition of archaeological kernels, her various charring regimes producing kernels that were either uncharred, or broken and fragile (neither of which would survive well in the archaeological record). She therefore also used parched rather than charred kernels to estimate change with charring. She found, with some variation, for 105 kernels of seven different cultivars the width and length increased about 3% but the thickness increased about 38% (King 1987:136). She also found that kernels previously boiled or made into hominy showed greater change after charring than did charred unprocessed kernels (King 1987:146–147). An experiment by Benz (1994), which used entire cobs rather than fragments, found that the charred cobs, although variably distorted, were still readily distinguishable as to race in a multivariate comparison.

These studies form a useful basis for understanding the effects of charring and processing, each pointing out directions for further work. First, a method must be found to char maize that replicates the appearance of archaeological kernels. Further, in any experiment the sample size should be substantial and include several varieties, the methods described in detail, and full range of variation in the resultant data presented.

In the present experiments we contribute to improved interpretation of ancient charred maize fragments by refining our assessments of the effects of charring and of various maize processing techniques. The experiments were designed to aid in analysis of charred fragmented maize recovered from sites in the Mantaro Valley (Johannessen and Hastorf 1989), an intermontane Andean valley in Peru, and the results should be applied with caution to other situations.

In the first experiment, which assesses the effects of processing, the shelled kernels of three varieties of Andean maize were processed by three common and ancient Andean techniques (toasting, sprouting, and boiling with wood ash) and the processed kernels were then charred. Kernels were measured and their characteristics were noted at each stage. In the second experiment, dealing with the effects of charring, a method of charring that replicates the condition of archaeological maize was developed. Then a sample of over 400 kernels and 200 cupules from ears of six modern Andean maize varieties were measured, charred, and remeasured, and the changes produced by the charring were analyzed statistically. These two experiments allowed us to replicate archaeological maize characteristics and provided insights into signs of maize processing that may remain in the archaeological record.

EXPERIMENT ONE: THE EFFECTS OF PROCESSING

In this experiment we wanted to see if different processing techniques resulted in distinctive kernels whose characteristics might be expected to survive charring and be distinguishable in the archaeological record. We tested the effects of three common Andean maize processing techniques on traditional varieties of modern maize. For each of the processes, we noted the appearance of the kernels before processing, after processing, and after the processed kernels were charred. Measurements and photographs were taken at each stage.

The three traditional processing techniques chosen were toasting, boiling with wood ash, and sprouting. Currently in the Peruvian Andes maize is commonly processed for ***kancha*** (toasted maize), ***mote*** (boiled hominy), and *chicha* or ***ahka*** (beer). For ***kancha***, kernels of soft or sweet maize are parched in a clay vessel over the fire until crunchy. For ***mote***, kernels are boiled with wood ash until the pericarp is loosened. These are rubbed off by hand, and the resulting *maiz pelado* (peeled maize) is dried for storage. For *chicha*, the kernels are soaked for several days and then kept moist until they germinate. The ***wiñapo***, or sprouted maize, is dried, milled, boiled with water, strained, and fermented to make the beer (Bird 1970; Cutler and Cárdenas 1947; Gade 1975; Mejía Xesppe 1978).

The antiquity of these processes is apparent in their descriptions in early ethnohistoric documents, and in old Quechua names such as ***moti***, ***camcha***, and ***wiñapo aque*** (*chicha* from sprouted maize) (Horkheimer 1973). Garcilaso de la Vega, born of an Inca mother in 1539, describes the traditional preparation of ***motis***, ***camcha***, and ***wiñapo*** as outlined above; "all this," he says, "I saw with my own eyes, and I was nourished until I was nine or ten with ***çara***, which is maize" (Garcilaso de la Vega 1985 [1609–1617]:341). Prehistoric maize processing has also been discernable in some archaeological examples. Dried germinated maize, presumably stored for *chicha*-making and dating to ca. A.D. 900–1400, has been recovered uncharred under very good conditions of preservation on the arid coast of Peru (Moore 1989). In wetter highland sites, however, where charring is necessary for preservation, the recognition of processed maize is more difficult. We wanted to see if these processing techniques resulted in characteristic kernels even after charring.

Materials and methods.—Gade (1975), Bird (1970), Cutler and Cárdenas (1947), Nicholson (1960), and Rick and Anderson (1949) discuss the varieties of Andean maize traditionally preferred for each of these three processes. For the experiment, we selected a characteristic variety for each process: the sweet corn *Chullpi* for making ***kancha***, the large-kernelled flour variety *Cuzco* for ***mote***, and a flour variety *Huilcaparu* for making *chicha*. The maize types were obtained in 1989 as shelled kernels in Bolivian markets in Cochabamba and La Paz. We chose shelled

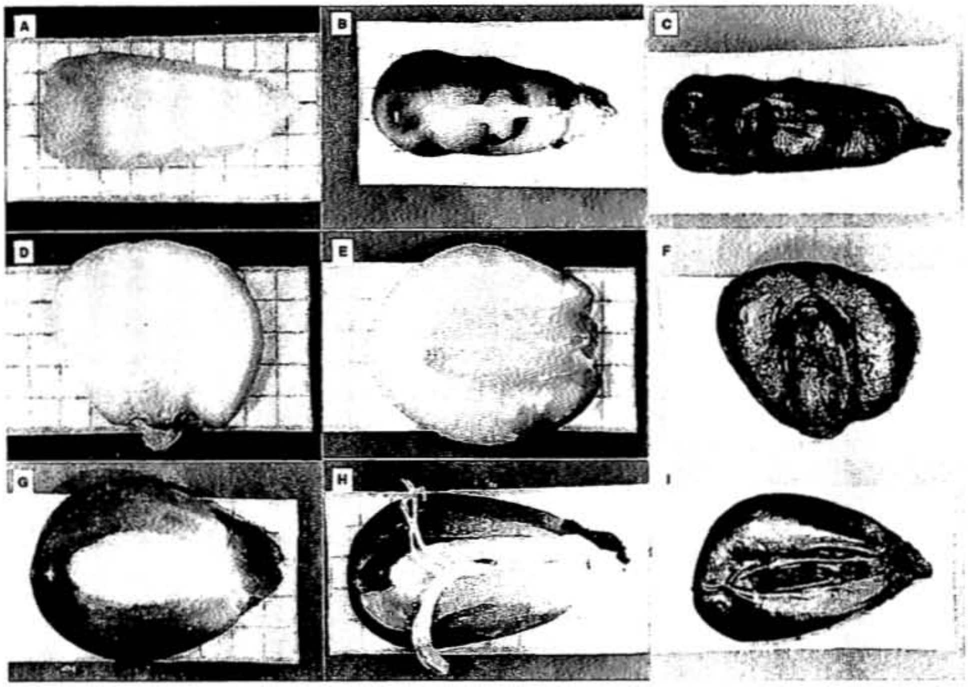

FIG. 1.—Kernels of three maize types at stages of the three processing techniques. A: unprocessed *Chullpi* (note the shriveled endosperm of this sweet corn); B: *Chullpi* toasted for ***kancha*** (shows vertical split down back of kernel); C: charred ***kancha*** (vertical split down embryo); D: unprocessed *Cuzco*; E: pericarp and point of attachment removed by wood-ash processing for ***mote***; F: charred ***mote***; G: unprocessed *Huilcaparu*; H: sprouted ***wiñapo*** for *chicha* (note pericarp over embryo pushed away by hypocotyl and radicle); I: charred ***wiñapo*** with hypocotyl and radicle burned away.

maize over whole ears because sources indicate that maize is traditionally graded and stored after shelling, and it is then this sample that is processed.

The *Chullpi* used for ***kancha*** is an Andean sweet corn with very long kernels (Fig. 1a). The ***kancha*** process is very simple; dried *Chullpi* kernels are placed in a clay pot (we used a ***kancha*** pot from the central Andes) over high heat. A handful of kernels is toasted in three or four minutes while stirring constantly. The resulting maize is toasted yellow with browned areas scattered across the swollen surface of the kernel. A distinctive crack in the pericarp occurs lengthwise either down the embryo area or the back of the kernel due to the puffing of the formerly shrunken "sugar" portion of the kernel (Fig. 1b). The radicle of the embryo protrudes upward through the cracked pericarp in many specimens.

Mote, which is similar to North American hominy, is prepared in the Vilcanota Valley of Peru with the large floury kernels of *Cuzco* (Fig. 1d) (Gade 1975). We used approximately one cup of hardwood ashes in two quarts of water to process 50–100 kernels of *Cuzco*. The water and wood ash form a lye solution with a pH of about 10. Once the ash and water mixture is boiling the kernels are added. The pericarps began to loosen after ten minutes of boiling over a medium-high flame. The kernels were then rinsed under running water while being rubbed together, removing any remaining pericarps and many of the points of attachment (Fig. 1e). *Maiz pelado* has a distinctive "hominy" smell and is light buttery yellow in color. Traditionally the peeled maize is added to soups or dried and stored for later use (Gade 1975). A second boiling in soup causes an enormous expansion of the kernels as they absorb water; the characteristic puffy appearance of ***mote*** or hominy results.

Huilcaparu is a variety widely grown and commonly used to make *chicha* in the Cochabamba Valley (Cutler and Cárdenas 1947:250) (Fig. 1g). The *chicha*-making process is long and complex, as illustrated by Cutler and Cárdenas (1947). Freshly sprouted kernels (the malted grains introduce the enzyme diastase that changes sugars to alcohol through fermentation) are dried and then milled. The resulting flour is boiled, allowed to settle, and the supernatant is removed for fermentation. The fermenting process takes 3–5 days.

The *chicha* processing technique we used was as follows: the maize was soaked overnight in water and a vermiculite mixture, and then sprouted for five days at 25°C in the moist vermiculite. When the majority of the kernels (15–20% of the kernels did not germinate) had radicles as long as the body of the seed, they were removed from the vermiculite and air-dried overnight. During germination the expanding radicle and hypocotyl pushed away the pericarp covering the embryo (Fig. 1h). The moist sprouted kernels were swollen to the limits of their pericarps, causing a puckered appearance across the tops of the kernels that was retained after drying. As the kernels dried, the radicle and hypocotyl became very delicate and broke off easily as did the pericarp covering the embryo. Nicholson (1960) states that in modern Peru the broken embryo parts are collected and saved for *chicha* production. Our processing sequence stopped here since in the next step the kernels are milled. Nicholson (1960) indicates that in the Andes maize is often sold or stored in the sprouted and dried state, and as we have seen, prehistoric examples of maize stored in this state have been found.

The products of these three processing techniques were then charred by the method described in the next section of this paper, in sand over a Bunsen burner with intervals of cooling. Samples of the sprouted kernels were charred both in the wet and dried state. The toasted ***kancha*** kernels unexpectedly took the longest time to char—up to 60 hours. The sprouted kernels took 24–50 hours, and the peeled and dried ***mote*** kernels took only 12 hours to char. The amount of endosperm extrusion (that is, the percentage of all charred kernels in which the endosperm expanded greatly with the heat and bubbled out through a split pericarp causing a fragile and greatly distorted kernel) ranged from 5–35% overall and correlated with the processing method. The ***mote*** kernels had the lowest percentage similar extrusion percentages of about 10–15%. The dry-charred *chicha* kernels had a very high extrusion percentage of 20–35%. This variation in the percentage of kernels that extrude with charring may be a reflection of the relative ability of kernels processed by various methods to become part of the archaeological record, since extruded kernels are very fragile and unlikely to survive.

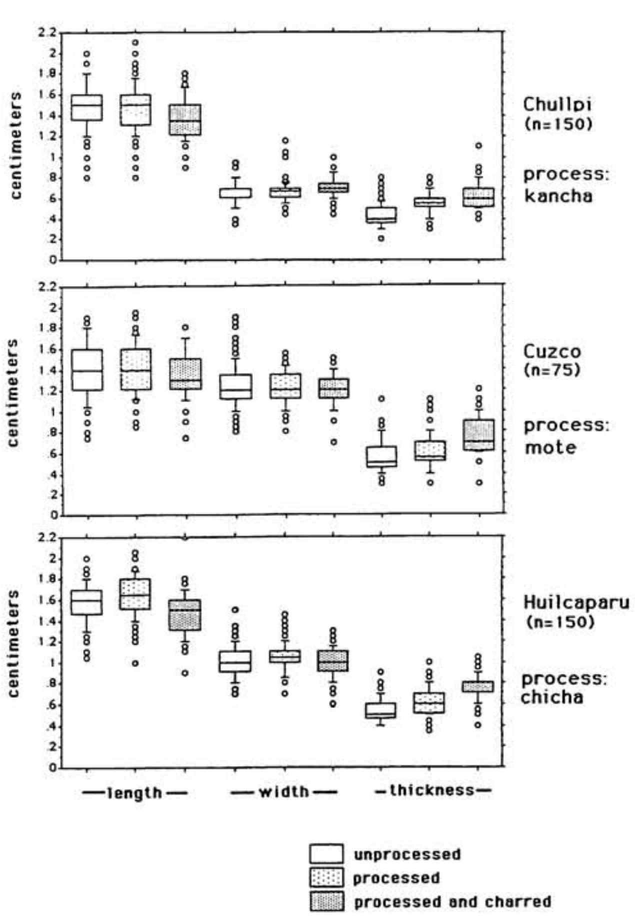

FIG. 2.—Range, variation, and change in the kernel measurments with processing and charring. The five bars of all box-plots mark the 10th, 25th, 50th (mode), 75th, and 90th percentiles.

To determine the metric changes resulting from the processing techniques, the kernels were measured at each stage; unprocessed, processed, and charred-processed. The measurements taken were length, width, thickness, and the angle of the two long sides (see below and Fig. 4 for details). One hundred and fifty kernels each of *Chullpi* and *Huilcaparu* and 75 kernels of *Cuzco* were measured at each stage.

Results.—Results of the maize kernel measurements are illustrated in Fig. 2, which shows the range of variability and change in length, width, and thickness with each stage of the three techniques. In general we see the same directional changes in the charred processed kernels as we do in charred unprocessed kernels (see below and Table 2). The greatest change is in increased thickness, with a slight decrease in length, and little change in width. Fig. 2 shows that in most cases the change in shape takes place during charring rather than processing. Table 1 gives

TABLE 1.—Average percentage change in kernel variables with processing and charring.

Maize type (process)	Chullpi (*kancha*)		Cuzco (*mote*)		Huilcaparu (*chicha*)	
Dimensions	P	P&C	P	P&C	P	P&C
length	−2.0	−8.0	+1.2	+4.3	+1.1	−9.7
width	+1.0	+4.5	−2.3	−4.2	+4.0	−1.6
thickness	+29.9	+39.0	+4.1	+38.0	+13.1	+42.8
angle	+31.0	+68.0	+15.6	+10.3	+5.8	+5.5

P: processed; P&C: processed and charred. Figures are percentage change in mean dimensions from the unprocessed kernels.

the mean changes in percentage for each type after processing and again after the processed kernels are charred. We can see by a comparison with Table 2 that the processed kernels get much thicker with charring than do the unprocessed kernels (mean increase of 40% as opposed to 13%), although the other dimensions undergo much the same amount of change. This confirms King's (1987) findings that processing does have a role in determining charred kernel shape, and further specifies that the major change is in the thickness.

Perhaps more important is the *appearance* of the charred and processed kernels (Fig. 1c,f,i). The toasted *Chullpi* ***kancha*** kernels kept their characteristic vertically cracked embryo or kernel back after charring. Even the protruding radicles survived charring intact. The browned and puffed areas of the pericarp became fragile after charring but the pericarp retained its integrity. Charring increased the overall puffiness of the **kancha** kernels. The sprouted *Huilcaparu* lost the delicate hypocotyls and radicles with charring, leaving holes where they had emerged from the embryo. The pericarp covering the embryo was also lost during charring. Processed and charred sprouted *Huilcaparu* kernels have a vertical crack down the embryo, similar to that of the toasted *Chullpi* kernels, but are distinctive in that their embryos are depleted and sunken. Those kernels most resembling archaeological maize were the carbonized lye-treated ***mote*** kernels. The endosperm of the *Cuzco*, having lost its restricting pericarp in processing, expanded greatly with charring. The expansion left the embryo with a sunken appearance. Although sunken, the embryo was still persistent on most kernels even after the boiling and charring processes.

Of the three processing techniques, the ***mote*** kernels were the quickest to char and were the most durable after charring, thereby making them the strongest candidates for preservation. In addition, they show the closest resemblance to much archaeological maize in lacking their pericarps, often their points of attachment, and occasionally their embryos. Processing maize with wood ash was a widespread practice in the Americas; the results of this process could make up much of the maize debris recovered from archaeological sites. King (1987:146) also reached this conclusion as a result of her experiments.

Conclusions.—We believe that the products of *chicha*, ***kancha***, and ***mote*** production, as produced in our experiments, would be distinctive in the archaeological record. The remains of *chicha* production could be identified by the distinctive radicle/hypocotyl holes and the missing embryo pericarp. The *chicha* characteristics might occur in any sprouted maize so archaeological context must be considered. ***Kancha*** kernels might be less distinctive because unprocessed kernels also puff during charring. However, the protruding radicle and the embryo crack would be good distinguishing characteristics for kernels that had been quickly parched over a hot fire. ***Mote*** kernels were the most distinctive products of the three processes in lacking the pericarp, often the point of attachment, and occasionally the embryo.

EXPERIMENT TWO: THE EFFECTS OF CHARRING

This experiment was designed, first of all, to devise a system of charring that would replicate the appearance of most charred archaeological maize. This would allow a more realistic estimate of the amount of distortion produced by such a charring method, and also provide insight into the kinds of conditions that may have preserved the maize we find archaeologically. Further, the experiment was intended to assess the effects of this charring on samples of kernels and cupules from a number of maize varieties. We concentrated in this case on loose kernels and cupules, rather than whole ears or cobs, since in our experience most charred archaeological maize is found in a fragmented state. Overall, 434 kernels and 221 cupules from six maize varieties were measured both before and after charring.

Materials and methods.—Specimens of six cultivars of modern Andean maize were used for this experiment. The varieties were selected to give variation in size, shape, and endosperm type so that differences in the effect of charring could be assessed. The six varieties are (1) *Confite puntiagudo*, a popcorn with small pointed kernels, (2) *Chullpi*, a many-rowed sweet corn, (3) an unnamed variegated flour variety with imbricated yellow and red striped kernels, (4) *San Geronimo*, a white flour variety, (5) *Morocho*, a flint type with characteristic round kernels, and (6) *Cuzco morado*, a dark red, large-kernelled 8-row flour variety (Fig. 3). The four endosperm types represented have the following characteristics. Popcorn grains are composed mostly of a very hard vitreous endosperm with a small amount of soft starch in the center. Steam generated in the soft center causes it to explode with heating. Flint-type kernels also have a hard translucent endosperm with starch in the center, the proportions varying by variety. In flour varieties the endosperm consists of soft starch. In sweet corn much of the sugars are not converted into starches with maturation, and the kernels are translucent and shrivelled when dry (Sturtevant 1899; Purseglove 1972:303–304).

Two ears of each variety were selected to provide the kernels and cupules for analysis. The two ears from each variety had the following row numbers: *Confite*, one 12-row and one 16-row; *Chullpi*, one 14-row and one 16-row; variegated, both 10-row; *San Geronimo*, both 10-row; *Morocho*, one 10-row and one with very irregular rows that was counted as 9-row; and *Cuzco morado*, one 8-row and one 10-row. The sample of kernels and cupules from the two ears of each maize variety is of

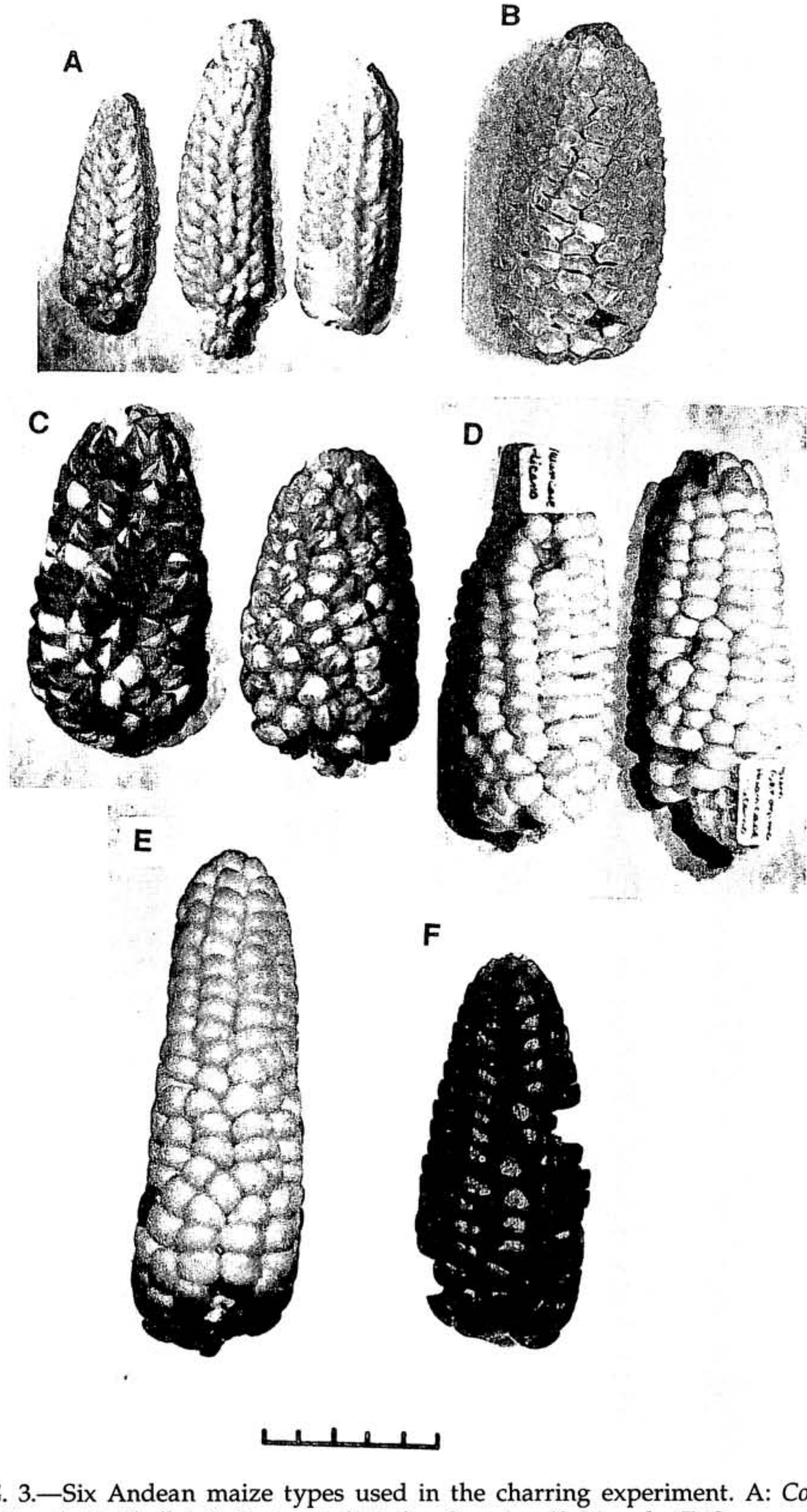

FIG. 3.—Six Andean maize types used in the charring experiment. A: *Confite puntiagudo*; B: *Chullpi*; C: Variegated; D: *San Geronimo*; E: *Morocho*; F: *Cuzco morado*. Scale is in centimeters.

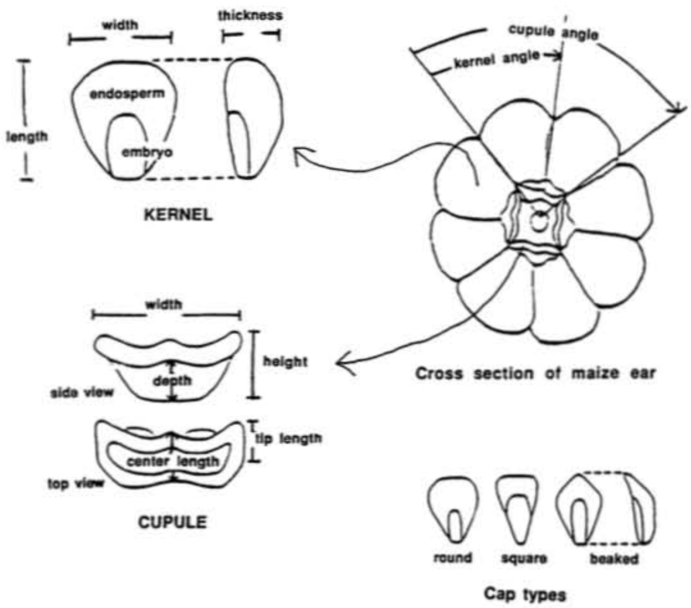

FIG. 4.—Kernel and cupule measurements used.

course by no means considered representative of the morphological variation within the variety as a whole; the emphasis here is rather on the change and variation that comes about with charring. The ears were all collected from Andean markets or farmers 6–10 years ago, and have since been stored in a herbarium cabinet, and thus were thoroughly air-dry.

Twenty percent of the kernels and cupules from each ear were measured. First, the length, center width, row number, and total number of kernels of each ear were recorded. All kernels were removed from each ear and 20% of the total were selected by picking blind-folded from a box. Selection of the cupule sample was more difficult, since cupules cannot readily be separated from an uncharred cob. Therefore, before charring, the cupule measurements had to be taken on the cob, and access to the cupules became the limiting factor in determining the sample. We experimented with sawing (Benz 1986), hammering, and hand-breaking to expose cob cross-sections. Because of the alternating arrangement of the cupule rows, sawing damaged the walls of the cupules, and hammering mashed the cupules. Hand-breaking best exposed a cross-section with intact cupules. Three breaks were made of each cob, one in the center and one toward each end. The cupules in the six exposed cross-sections were those used in the study, for roughly a 20% sample from each ear.

Measurements of the kernels and cupules taken before and after charring were those that can readily be taken on archaeological specimens (Fig. 4). Kernel measurements were length, width, thickness, and angle of the two long sides. Kernel cap types were coded as round, square, or beaked. Cupule measurements were width, height, depth, center length, wing length, and angle. All measurements except angles and cupule depth were taken with sliding calipers to the nearest 0.05 cm. Angles were measured to the nearest 5° by laying the kernel or cupule on a piece of laminated polar coordinate graph paper (delineating the 360° of a circle), lining one of the long sides on the 0° line and moving the kernel or cupule until the other long side was flush with a degree line. Cupule depths were measured from the front lip to the deepest part of the cupule pocket using a calibrated metal probe.

Previous experiments in charring maize have resulted in extensively swollen, broken, extruded and fragile kernels (King 1987; Pearsall 1980). Not only are such kernels unlikely candidates for preservation, but both King and Pearsall note that archaeological maize remains often appear well-preserved with little apparent distortion, although often the kernel embryos are missing as well as much of the pericarp. The ancient conditions of charring that produced such maize remains have thus far been unduplicated experimentally.

In this experiment we tried a number of charring techniques to find that which produced the least fragile and least distorted charred maize fragments. The most successful method was slow charring in a reducing atmosphere at relatively low temperatures, with periodic intervals of cooling. Test kernels and cupules were charred in sand over a Bunsen burner at a temperature of about 180–190° C. The fragments were heated for 1.5 hours, allowed to cool completely, heated again for 1.5 hours, cooled, and so on until completely charred through to the center. This method took an average of 16 hours burning time to char one sample of kernels. Kernels charred at the same temperature but without the cooling intervals showed more frequent endosperm extrusion; 25% of the kernels as compared to 17% with the cooling intervals. Cupules were charred on the cob using the same method, with a shorter charring time of 10–12 hours per cob. We found that kernels and cupules left to burn after they have been fully charred retain their integrity. They do not disintegrate, crumble, or become more fragile.

The kernels and cupules from the six modern Andean maize varieties were then charred following this successful method, and the charred fragments were remeasured.

Change in kernels and cupules.—The maize kernels generally became shorter, wider, and thicker with charring. The percentile box-plots in Fig. 5 show the range of variation and the change with charring in length, width, and thickness for each of the six maize types. The box-plots have the properties of (a) showing the central tendencies and full range of variation for the samples for each maize type and each variable, and (b) allowing comparison of sizes and shapes among varieties. Overall *mean* change for the kernels consisted of a 6% decrease in length, width was minimally affected with an increase of only 1%, and thickness increased most to an average of 13% (Table 2). These findings differ from previous experiments using parched maize (King 1987; Pearsall 1980), where it was reported that all three dimensions increased. The measured angles of the kernels undergo a slight average increase of about 6%. The kernel caps tended to become slightly more round; 8% of the square cap types and 6% of the beaked types became round after charring. Two indices useful in describing the shape of kernels from the front and the top, ratios of width/length and width/thickness respectively, also change with charring. Since width generally increases as length decreases, the width/

TABLE 2.—Average percentage changes due to charring in six maize types. Figures show direction and percentage of change before and after charring.

Dimensions	Confite	Morocho	Chullpi	Cuzco	San Ger	Variegated	All Ears
Kernels	(n = 94)	(n = 64)	(n = 85)	(n = 75)	(n = 72)	(n = 54)	(n = 437)
Length	−1.4	−3.7	−7.6	−4.1	−6.8	−8.8	−5.5
Width	−0.4	+3.6	+2.0	0.0	+0.8	−0.6	+1.2
Thickness	+10.4	+17.2	+13.1	+20.6	+10.0	+5.1	+12.5
Angle	−2.7	+6.7	+1.6	−1.9	+21.2	+13.4	+5.5
Cupules	(n = 47)	(n = 32)	(n = 42)	(n = 37)	(n = 36)	(n = 27)	(n = 221)
Height	+6.0	−14.9	−9.1	−12.3	−12.7	−10.3	−8.2
Width	−15.7	−13.5	+6.3	−8.6	−17.1	−8.4	−9.7
Depth	−38.5	−18.2	−54.5	−22.7	−4.0	−29.1	−30.5
Center Length	+9.6	+14.8	+44.8	+23.4	+26.7	+57.8	+26.4
Wing Length	+9.7	+14.6	+44.2	+0.6	+2.8	+37.0	+15.7

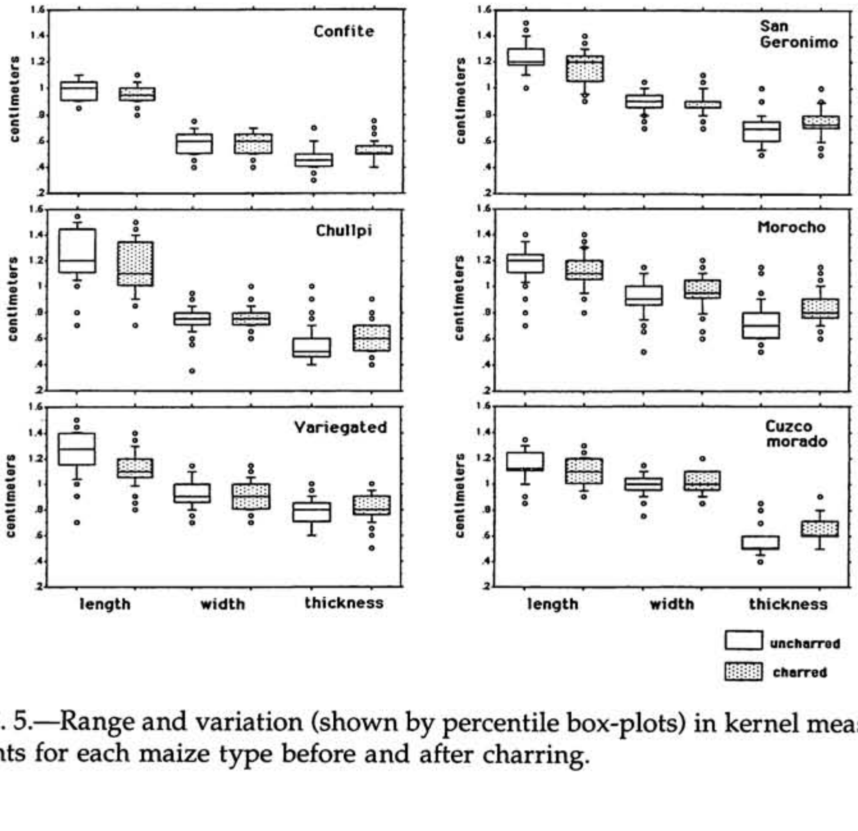

FIG. 5.—Range and variation (shown by percentile box-plots) in kernel measurements for each maize type before and after charring.

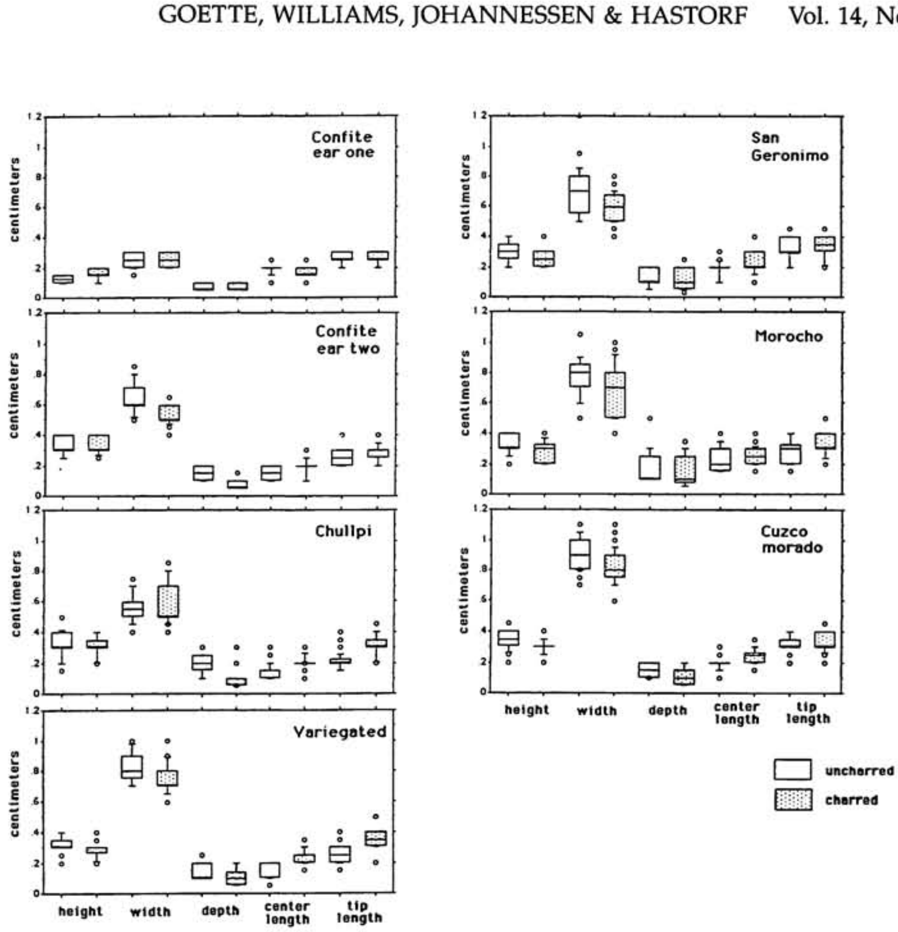

FIG. 6.—Range and variation in cupule measurements for each maize type before and after charring. Measurements for the two ears of *Confite* are shown separately, because it was found after removal of the kernels that the cupules of the two ears were quite different.

length ratio increases an average of 7%. Since thickness increases more than width, the width/thickness ratio decreases due to charring by an average of 12%. Fig. 5 and Table 2 show that although kernels of most varieties show the same general tendency for increase or decrease in each variable, the amount of change varies considerably. The amount of change does not correlate with endosperm type; the three flour varieties together show a wider range of variation than among the three other endosperm types (pop, flint, and sweet).

For the cupules, we found that the cupule height, depth, and width decreased while the center and wing lengths increased with charring (Fig. 6). Mean overall change consists of a 8% decrease in height, a 30% decrease in depth, a 10% decrease in width, a 30% increase in center length, and a 16% increase in wing length. Table 2 shows that, again, while the *direction* of change was consistent in most varieties the *amount* of change varies greatly.

Predicting row number from angle.—The row number of a ear of corn is held to be among the more reliable indicators of its variety (Bird 1970; Cutler and Blake 1973; Goodman and Paterniani 1969). With fragmented archaeological maize where the row number can no longer be counted from the ear or cob, many researchers have used the angle measured on the two long sides of a kernel or cupule to approximate the original row number. This is based on the portion of the 360° occupied by the kernel or cupule; in an eight-row ear, for example, a kernel will occupy 45° (one-eighth of a circle) and a cupule 90° (each cupule bears two kernels). However, this angle can be affected by the fact that kernels are generally offset slightly so that their edges do not abut, and in some types the rows are irregularly arranged. Thus the generalization that row number = 360/ angle-of-kernel (or row number = angle-of-cupule X 2) does not necessarily reflect reality. Some attempts have been made to assess the accuracy of the angle method of determining row number. Pearsall (1980) measured the angles of 25 kernels from ears of known row number (8, 10, 12, and 14-row cobs), with limited success in predicting row number. She found that the 8- and 10-rowed measured as either 8 or 10 but couldn't be further segregated; that kernels from 12-row ear measured as 8, 10, or 12-row; and that the 14-row measured fairly accurately. The measurements were made by the Cutler and Blake (1973) method of best-fit of the kernel to a number of pre-cut angles of 45° (8-row), 36° (10-row), and so on. Bohrer (1986), in an experiment measuring the kernels from two cobs (12- and 14-rowed), found that only 31% of the kernels from the 12-row cob and only 7% of the kernels from the 14-row cob gave measured angles that would have classified the kernels correctly. She does not state how the angles were measured. King (1987:128–129) found from measuring the angles of 160 kernels of eight varieties (measured by photo-copying the kernels and then drawing and measuring the angles), that 68% of the kernel angle measurements resulted in incorrect row number determinations.

We tested the degree of accuracy of using angles to predict row number by plotting the measured angles against the angles calculated from the actual row number of the original ears. Fig. 7 shows the scatterplots, regression, and correlation for actual vs. expected angle for the kernels (uncharred and charred) and for the charred cupules (uncharred cupule angles could not be measured since they couldn't be detached from the cob). The figure shows considerable variation in the measured angles of kernels from ears of the same row number, and overlap between and among row numbers. For uncharred kernels, only about 43% of the total variation in measured angles is attributable to the difference in row number. The predictive value of angles measured on the charred kernels was somewhat better ($R^2 = .57$). The angles measured on charred cupules were the best predictors of row number ($R^2 = .64$). This may be due to the fact that the expected angles of cupules are farther apart than those of kernels by a factor of two. In other words, 60° and 72° (cupule angles from 10- and 12-row cobs) are more easily discriminated than 30° and 36° (kernel angles from 10- and 12-row cobs).

An analysis of variance, however, does reveal significant differences (at 95%) in angle measurements between samples from most row numbers. The mean angle measurements of the kernels and cupules were very close to their expected angles (Fig. 8) in most cases. However, the kernels from the 14-row ears and the

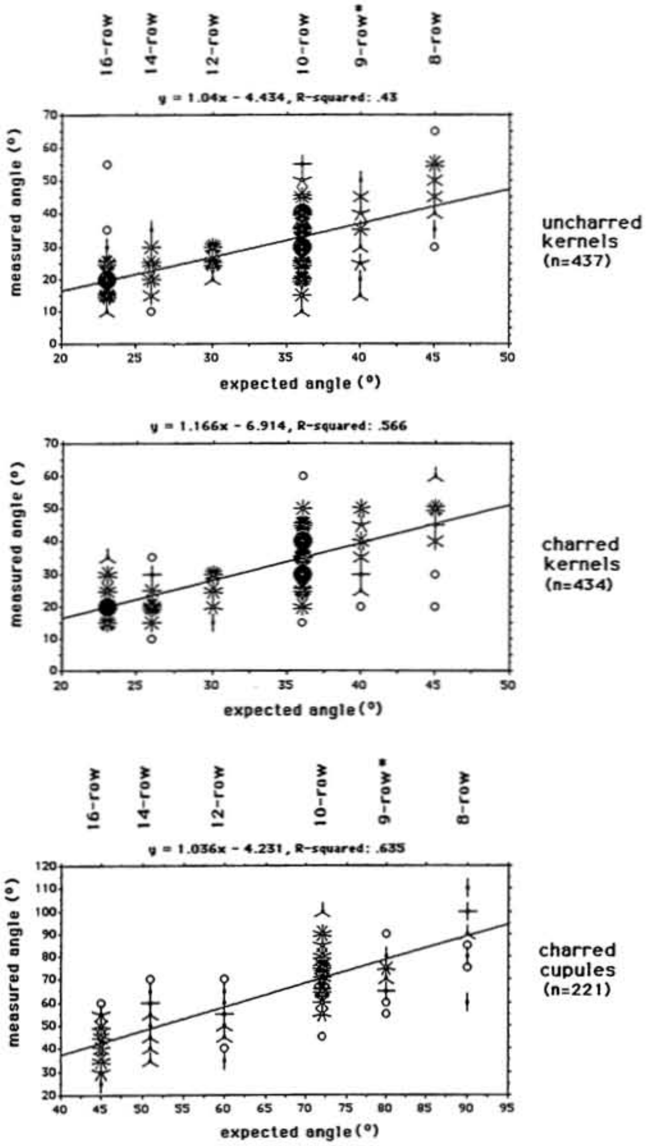

FIG. 7.—Describing variance in measured angles. Scatterplots, regression, and correlation of the measured vs. expected angles assess the accuracy of using kernel and cupule angle measurement to reconstruct row number. Overlapping points are indicated by "sunflowers." *One ear with uneven and varied rows was counted as a 9-row ear.

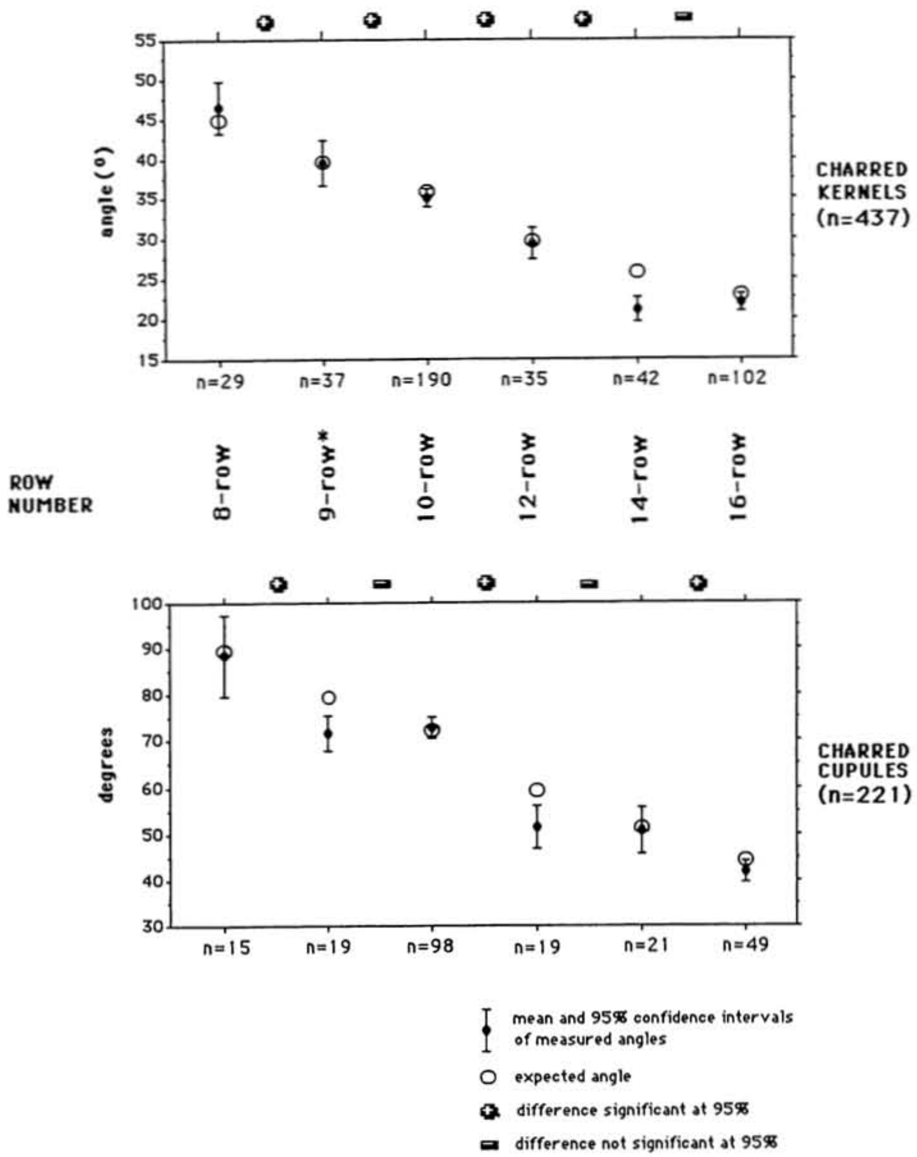

FIG. 8.—Analysis of variance in measured angles. The figure shows the mean angles and 95% confidence intervals of kernel and cupule samples from different row numbered ears, compares sample means to expected angles, and indicates the significance level of differences between groups (derived from analysis of variance).

cupules from the 9-row (one ear of *Morocho* had irregular and varied rows and was counted as being 9-row) had measured angles lower than expected, and thus the differences between the 14- and 16- row kernels and the 9- and 10-row and the 12- and 14-row cupules were not significant statistically. This suggests that measured angles from kernels and cupules often do reflect the actual row number *on a statistical* basis, although measurements on individual fragments have limited accuracy.

A note on processing.—An unexpected outcome of the experiment was the condition of the charred kernels. Of over 400 kernels, none lost their pericarps or embryos during the burning process. Charred archaeological kernels, otherwise well-preserved, are often missing all or most of their pericarps and often their embryos, and we have tacitly assumed that these were lost during the charring process. However, this may not be so, since in this experiment every kernel without exception retained its pericarp and embryo intact, even after 20 hours of burning. It seems plausible that the loss of pericarp and embryo from archaeological kernels with minimal distortion may have resulted from processing *before* they became charred, rather than from the charring itself. This bears out the findings from the experiment described above, from which we concluded that kernels processed with lye to remove their pericarps have the best chance of being preserved in the archaeological record.

SUMMARY, DISCUSSION, AND CONCLUSIONS

Our first experiment resulted in distinctive appearances for charred maize kernels subjected to three common Andean forms of processing. There is presently enormous variation in the maize varieties preferred for ***mote***, ***kancha***, and *chicha*, and it is probably safe to assume that the prehistoric people of the Andes had as widely varied tastes as the modern residents. Since we know that different types of maize react somewhat differently to charring, we cannot make a direct comparison between the appearance of archaeological maize and our modern processed and charred maize. However, we believe that the distinguishing characteristics described in Experiment One are the results of the processing method and not just the maize variety.

We cannot predict how hundreds of years in the soil affect charred maize. The grinding force of freezing and thawing could wear away at the persistent but fragile pericarps of ***kancha*** and *chicha* kernels leaving them naked like ***mote*** kernels. The embryos of the kernels could be preferred by animals or soil microbes, removing them before complete charring occurred. We can only suggest the many forces that could occur before, during, and after deposition, and thus cannot make direct comparisons between experimental processed and charred kernels produced in the laboratory and those recovered from archaeological sites. But we do know that charred processed maize is quite distinct from unprocessed charred maize, and that the results of the three methods were distinct from each other, and that these attributes may be preserved in ancient kernels. Finally, we recognize ***mote*** or hominy (pericarps removed by boiling with lye) as the process that results in maize most likely to be preserved and most resembling the condition of archaeological kernels.

In the second of these experiments we found a method of charring maize successfully, and assessed the effects of charring on the size and shape of the kernels and cupules of six varieties of maize. Long, slow, intermittent heating in a reducing atmosphere produced charred kernels and cupules that were not excessively distorted or fragile; i.e., were good candidates for the kind of long-term preservation we see in archaeological maize fragments. These conditions may be similar to those that charred the ancient maize that we find—burial in soil or ash near hearths that were periodically kindled.

Our research question concerned the degree to which measurements taken on charred maize fragments accurately reflect attributes of the original material. We found (a) that all measurements taken on a kernel or cupule are not affected to the same degree by charring, therefore the fragments change in shape as well as size; (b) kernels generally stay about the same width, and get slightly shorter and quite a bit thicker, while cupules decrease in all dimensions except length; (c) whereas the *direction* of change in a certain dimension was generally the same for the six varieties, we found considerable variation in the *amount* of change among varieties. Therefore no formula will entirely accurate in reconstructing the precharred attributes of maize kernels or cupules. Our results suggest generally that kernels stay about the same width, get about 5% shorter, and about 15% thicker, thus affecting the shape of the kernels, especially the width/thickness ratio. The height and width of cupules were found to decrease about 10%, and the length to increase roughly 20%, so that the most radical change is in the shape of the cupule from the top, becoming longer and narrower. We also found, as have previous researchers, that angle measurement of single kernels and cupules is not an accurate predictor of row number, having about 50% or less chance of accuracy with kernels and a somewhat better chance with cupules. However, the mean of a sample of measurements does often accurately reflect the row number.

Our experiments have detailed the effects of only a few of many possible conditions of charring and processing. The variation in morphological changes in charred maize kernels and cupules, as well as the many unknown biases that occurred in the processes of deposition, preservation, and recovery, make the reconstruction of ancient maize types and their uses a daunting problem. We believe that the most fruitful avenue of research lies in a combination of multivariate statistical analysis of large systematic samples of ancient maize fragments, and continuing experimental work, not only on the conditions producing morphological change, but on the structure of variability within and between maize types (Johannessen et al. 1990; Johannessen and Hastorf 1989).

All will agree that it is risky to draw conclusions about types and usage from a small sample of archaeological maize fragments. Nevertheless, standardized description and reporting of the raw data (so as to give the full range of variability) from even small samples can eventually build up large data bases that in conjunction with results of experiments on modern maize can give a more confident picture of local and regional patterns of ancient maize use.

ACKNOWLEDGEMENTS

We wish to thank Frances King and Deborah Pearsall for advice in designing the experiments. The research represents two Research Experiences for Undergraduates grants awarded under National Science Foundation grant BNS 84–51369.

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BOOK REVIEW

Oat Bran. Peter J. Wood (editor). St. Paul, Minnesota: American Association of Cereal Chemists (3340 Pilot Knob Road, St. Paul, MN 55121–2097). 1993. Pp. 164. $90. No ISBN given.

This compact volume of six chapters by nine recognised experts satisfies a need which is clearly set forth in the Foreword by the editor, Dr. P.J. Wood: "In 1989, the public appetite for oat bran was at its peak. Both the product itself and media reports describing miraculous health benefits were avidly consumed. . . . the American Association of Cereal Chemists. . . . suggested that a book be compiled that would attempt to describe the nature of oat bran, its means of manufacture and properties and what was known about its physiological effects." This book fully satisfies the worthwhile attempt to set forth the actual facts and it does it with full coverage of the subject.

The chapters describe: 1) Structure of Oat Bran and Distribution of Dietary Fiber components (R. Gary Fulcher and S. Shea Miller); 2) Current Practice and Novel Processes (D. Paton and M.K. Lenz); 3) Comparisons of Dietary Fiber and Selected Nutrient Compositions of Oat and Other Grain Fractions (J.A. Marlett); 4) Physiochemical Characteristics and Physiological Properties of Oat (1–3), (1–4)-B-D-Glutean (P.J. Wood); Physiological Responses to Dietary Oats in Animal Models (F.L. Schinnick and J.A. Marlett); 6) Hypocholesterolemic Effects of Oat Bran in Humans (J.A. Anderson and S.R. Bridges). Each chapter contains a comprehensive bibliography of literature cited, and there follows a detailed index.

The American Association of Cereal Chemists has published a number of outstanding books which I have reviewed. I consider this volume to be one of the finest, particularly from the point of view of coverage and presentation of the latest scientific data which corrects some of the misunderstandings and misinformation that has been in circulation.

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