C. Hastorf

TOWARDS INTERPRETING ANCIENT MAIZE:
Experiments in charring

A THESIS
SUBMITTED TO THE FACULTY OF THE COLLEGE OF LIBERAL ARTS
OF THE UNIVERSITY OF MINNESOTA
BY

Susan Goette

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
BACHELOR OF ARTS
Summa cum laude

May, 1990

"Birds Being Chased from the Maize Plants"

Guaman Poma de Ayala, Felipe
1975 [1615] Nuera Cronica y Buen Gobierno. Edited by John V. Muna and Jorge L. Urioste. Madrid: Historia 16. (picture is from page 1211)

INTRODUCTION

Maize (Zea mays spp. mays) has played a significant role in the lives of New World peoples since its domestication. It is a very diverse plant, grown from Canada to South America, with varieties that encompass a wide range of shapes, sizes and colors. Maize has been grown for nutritional, religious and economic use. How people use maize affects peoples choice of variety since particular types of maize are more suited to some uses than anothers (Grobman et al, 1977). People recognize and classify maize based on specific kernel and cob characteristics. Because of this relationship between maize types and their use, (Bird & Goodman 1978) paleoethnobotanists and archaeologists have been able to use information from maize ears to talk about the cultural role of maize. But in studying prehistoric maize, we are often faced with the problem that the only remains we have to study are the burnt fragments of ears.

While maize fragments are abundant in the archaeological record, often little has been done with these fragments in the belief that too much information has been lost. Current researchers have challenged this belief by proposing methods for assessing what prehistoric corn may have looked like based on charred remains. These studies suggest that we can gain information about row number and kernel size and shape from maize fragments. The experiments of King (1987), and Pearsall (1980) report changes in kernel shape and size based on the morphological comparison of burnt and unburnt corn. Guided by the work of Cutler (1956) and Cutler & Blake (1973), three ethnobotanists, Bohrer (1986), King (1987), and Pearsall (1980), independently assessed the reliability of predicting the row number of an ear of corn from the angle of the kernel. Researchers have concentrated on the relationship between angle and row number because row number is recognized as an important criteria for distinguishing cultivars, (Goodman and Paterniani 1969, Cutler and Blake 1973). Further, King (1987) describes how differing endosperm types change shape when subjected to charring, while Doebley and Boher (1983), classified charred kernels based on endosperm characteristics. This information helps to refine the accuracy of kernel reconstruction.

In any study that tries to link prehistoric maize to modern maize, reproducing charred maize kernels has proven to be a problem. Both Pearsall (1980), and King (1987), who did the most extensive work on reconstruction, were limited by their use of parched corn and the inability to sucessfully char popcorn. We decided that their findings could best be confirmed or revised if a successful method for charring maize could be developed. To this end, we turned our attention to charring both kernels and cupules of comparative modern types.

In the present experiment we have attempted to improve the interpretation of ancient charred maize fragments by reproducing charred maize from modern varieties. Through a series of experiments we have developed a charring process that produces maize fragments closely resembling archaeological maize. We believe this process has strong implications for possible prehistoric charring conditions and practices. Further, that this process will allow paleoethnobotanists to reconstruct the precharred size and shape of prehistoric maize.

MATERIALS AND METHODS

A systematic sample of maize fragments from twelve ears of six modern Andean maize cultivars were measured, charred by a method replicating the condition of archaeological maize, and remeasured. We looked at shape changes caused by charring, determined the accuracy of predicting row number from both kernel and cupule angle, and compared the direction and amount of distortion across endosperm types.

Sampling

Specimens of six varieties of modern Andean maize were used in the experiment, and are pictured in Figure 1. The varieties selected varied substantially in size, shape, and endosperm type, allowing us to assess the effects of charring on different cultivars. The six types were: 1) Confite Puntiagudo,[1] a popcorn with small pointed kernels; 2) Chullpi, a sweet corn; 3) Morocho, a flint type with characteristic round kernels; 4) Cuzco Morado, a large-kerneled, eight-row, flour variety; 5) San Geronimo-Huancavelicana, a white flour variety; and 6) a variegated flour variety with imbricated yellow and red stripled kernels.

The study included four endosperm types: popcorn, flint, flour, and sweet. The endosperm (fig. 2) consists of the bulk of the kernel and varies in texture depending on the type, (Sturtevant 1899, Purseglove 1972: 303-304). Popcorn grains are composed of a very hard, corneous, dense endosperm with a small amount of soft starch in the center, therefore when it is heated steam generated in the center causes it to explode. Flint type kernels also have a hard translucent endosperm but with a larger amount of starch in the center, whose proportions vary by variety. In flour varieties, the endosperm consists of soft starch. The kernels of sweet corn are translucent and shrivelled when dry because many of the sugars are not converted to starches with maturation. The study used two ears per variety from six varieties of maize: 1 popcorn, 1 flint, 1 sweet, and 3 flours. Three flour varieties were included because the number of known Andean flour varieties far exceeds any other endosperm type. Statistically, a larger number of ears per variety would have been preferable to the two ears per variety used in the study. Because our collection did not contain a large number of ears of the more ancient varieties, and because we judged it important to include them, we decided to use only two ears per variety. Ears were collected from Andean markets or farmers 6-10 years ago, and have been stored since then in a herbarium cabinet at the University of Minnesota archaeobotany laboratory. Thus, they were thouroughly air-dried before being charred. Once selected, all maize ears and subsequent kernels and cupules removed from these ears received an ear designation code, defined in Table 1 along with cultivar, row number, and endosperm type.

Kernel Sample

First, the length, center width, row number and total number of kernels for each ear was recorded. All kernels were removed from each ear, and 20% of the kernels from each cob were selected by pulling blind-folded from a box. Kernel selection was done one ear at a time. The analyzed sample totaled 441 kernels (Table 1).

Cupule Sample

Selection of the cupule sample was more difficult. We could not select them individually because cupules do not readily separate from an uncharred cob. Further, height was determined to be an important measurement and can only be taken on an exposed cross section of the cob. Due to these restrictions, access to cupules became a factor in determining the sample. We experimented with hammering, sawing (Benz 1986), and hand breaking methods to expose cross sections of the cob. Hammering mashed the cupules that absorbed the blow and because of the alternating arrangement of the cupule rows, sawing damaged the walls of the cupules. Hand breaking the cobs, however, left the entire cupule intact. Access to cupules was limited by the number of breaks per cob. A break was made at the center of each cob, plus one additional break toward each end of the cob, totaling three breaks. Increasing the number of breaks tended to distort cupule shape because cob length was generally short, ranging from 6.6 cm to 12.4 cm. Cupules on the exposed cross sections became the cupules included in the study. Again, we used a 20% sample from each cob. The sample consisted of 221 cupules (Table 1). [2]

MEASURING TECHNIQUE

The measurements of the kernels and cupules taken before and after charring were those that can readily be taken on archaeological specimens. All measurements, except for kernel angle, cupule angle and cupule depth, were taken with hand-held sliding calipers and measured to the nearest .05 cm. Measurements taken are illustrated in Figure 2.

The Kernel

Kernel measurements were choosen for their collective ability to describe most completely the shape and size of the kernel. Measurements included: kernel length, width, thickness, and angle. Kernel width and thickness were taken at the widest point. Kernel angle, used to calculate the row number of the ear, was measured as the angle of the two long sides of the kernel. This calculation is based on the shape of the cob, which is circular in cross section, with each wedge shaped kernel occupying a section of the 360^{o} formed by the circle. If the kernel angle is 45^{o}, 8 kernels could fit around the cob, indicating an eight rowed cob. Similarly, a 36^{o} angle indicates a 10 row cob, and a 30^{o} angle indicates a 12 row cob, and so on, (King 1987, Pearsall 1980, Cutler 1956, Cutler and Blake 1973). The ability to calculate the row number of an ear from maize fragments is important since row number is very useful in differentiating maize varieties (Goodman and Paterniani 1969, Cutler and Blake 1973). To measure kernel angle this study used a piece of laminated Polar Coordinate Engineering

Form graph paper which delineates the 360 degrees of a circle, in 5 degree increments. Individual kernels were placed on the paper and examined under a light stereoscope. Angle was determined by lining up one of the long sides of the kernel on the 0° line, and moving the kernel until the other long side was flush with another degree line. This became the angle measurement. The shape of the kernel cap was also recorded as round, square, beaked, or fat-backed; illustrated in Figure 2. Two ratio variables, incorporated into the study, width/length and width/thickness, reflect the shape of the kernels from the front and from the top, respectively, (King 1987, Pearsall 1980). Figure 3 displays the typical kernel shape, shown from a front and a side view, of each variety in this study.

The Cupule

The concave shaped cupule, in which a pair of kernels sits, exists as the hardest structural part of the cob. Its shape varies from an elongated form as in Confite Morocho, (CP1), to the compressed but wider form of Cuzco Morado, (CM1), (fig. 3). Researchers have applied cupule measurements (fig. 2) to a wide range of prehistoric and modern specimens. (Benz 1986, Bird & Bird 1980, King 1987, Miksicek et al. 1981, and Nickerson 1953). Measurements used in this study include: cupule width, center length, height, angle, wing length, and depth. Both Benz (1986) and King (1987) have used wing length and depth to aid in describing cupule variability.

Cupule width is measured across the aperture from the outer edge of the cupule wings. Cupule center length is measured as the distance from the cupule apex to the outside of the front lip. Cupule angle was determined in the same manner as kernel angle. Height is taken from the bottom of the cupule to the highest point of the cupule wings. Cupule wings are the "flared margins on either side of the cupule oriented parallel to the longitudinal axis of the ear," (Benz 1986:114). Wing length is measured at the longest point. These wings are most pronounced in the variegated variety shown in Figure 3. Cupule depth, the distance from the front lip to the deepest point in the bottom of the cupule cavity, was measured to the nearest .05 cm with a homemade calibrated metal probe, developed for this study by Goette.[3] We felt that these measurements, as a group, best captured the shape and size of the cupules. Figure 3 illustrates the typical cupule shape of each variety, shown from both a front and a top view.

CARBONIZATION PROCESS

> "As maize is heated, conversion of water to steam in the kernel causes it to swell. As heating is continued to the point of carbonization, . . . internal pressures force the contents of the kernel out through splits in the pericarp.
> Sudden release of pressure causes the extruded endosperm to expand and it forms a black matrix surrounding the pericarp. The kernels are often hollow and nearly as fragile as their endosperm matrix. (None) seemed a good candidate for long term preservation in archaeological sites from which the recovered maize often appears well preserved with little apparent distortion." Frances King (1987:133)

Surviving maize kernels from the archaeological record tend not to have the endosperm extrusions described by King. Characteristically, these surviving kernels are missing their embryos and retain at most only fragments of their pericarp, the hard, transluscent hull surrounding the kernel. We needed a charring process that would produce a sample with a high rate of intact whole kernels and cupules and a low rate of endosperm extrusion. We believe this type of sample would most closely resemble the archaeological specimens available to researchers.

It is important to keep in mind that this experiment was not an attempt to re-create the conditions or processes that gave rise to the preservation of maize, rather, it was an attempt to produce kernels that most resemble those in the archaeological record. Given the high number of theoretically possible processes that could have affected archaeological maize (i.e., burning in an open flame, a field, an oven, a kiln, or a hearth), we decided to focus our attention on the characteristics of archaeological kernels and cupules we could observe. Of special note however, in the process of producing charred kernels, we believe we found a procedure that appears to mimic prehistoric charring conditions.

CHARRING METHODS

Based on our observation of archaeological maize, a successful method of charring would produce kernels with minimum distortion (the least possible number of endosperm extrusions) and maximum strength, whole and intact kernels. To find a sucessful charring strategy, six charring methods were designed and tested. Each met with differing degrees of success. The fifth method produced kernels closely resembling archaeological maize. Each method was tested on non-sample kernels and cupules from modern varieties of Andean maize.

Method I The Marshmallow Method

This method consisted of burning individual cupules and kernels in an open flame, similar to roasting marshmallows on a stick. Method I completely charred both cupules and kernels in less than a minute. The kernels exhibited no endosperm extrusions. The pericarp of the kernels turned to ash, leaving the inside of the kernel carbonized but extremely fragile. The cupules fared somewhat better. They were less fragile with very little ash. Method I produced a kernel without its pericarp, similar to archaeological maize, but the remaining endosperm, unlike archaeological maize, appeared too fragile to survive; therefore we rejected Method I.

Method II The We'll Try Anything Method

In an attempt to better understand conditions that would reduce endosperm extrusion, whole ears with kernels still attached were burned in a reducing environment of fine grained sand 6.5 cm deep inside a metal container measuring 12.5 cm in diameter. The container sat on a tripod 4.5 cm above a bunsen burner set on a low flame. The ears burnt for 4 hours at a temperature that ranged from 175 - 225 degrees centigrade. This method produced kernels with little endosperm extrusion. When compared to the loose kernels charred by Method III, we found that whole ears can withstand higher temperatures, consequently whole ears will char faster than individual kernels. Although Method II could not be used on the samples in the experiment, this method demonstrated that it is possible to char maize without endosperm extrusion. explain why

Method III   The Continuous Burning Method

Method III was designed to provide us with a base line of information about the effects of charring on individual kernels. This method utilizes the same container, tripod distance, burner and temperature as Method II. This time loose kernels of differing endosperm types were placed in the sand. This produced a group of charred kernels with an endosperm extrusion rate of 40%, (40% of the sample had endosperms that extruded, or, as in the case of popcorns, exploded). We rejected Method III because it did not char popcorn.

Method IV   The Interrupted Method

Using the same set up as Methods II and III, loose kernels placed in sand were heated for 1 1/2 - 2 hrs, then allowed to cool completely. They were heated again for another 1 1/2 - 2 hr interval, and then cooled again. These heating and cooling intervals were repeated until complete charring took place. The effect of the intervals was to reduce the temperature to about 200 degrees centigrade. Method IV sucessfully charred popcorn and reduced the extrusion rate to 30%.

Method V It Can't Possibly Take That Long

This method utilizes the same container, tripod, distance and burner as Methods II and III. This method also incorporates the heating and cooling intervals of Method IV, but focuses on further reducing the extrusion rate. To do so, this time a rock, 4 cm thick, made of cement and large gravel, was situated on the tripod between the metal container and the heat source to act as a damper by dissipating the heat. With the addition of the damper, the distance between the heat source and the container became 8.5 cm. This set of conditions produced a sand temperature that ranged between 180 - 190 degrees centigrade (355 - 375 degrees fahrenheit). Method V, the most sucessful method thus far, dropped the extrusion rate to less than 17%. To better understand the factors affecting endosperm extrusion, we continued the experiment with Method VI.

Method VI Just One More Variation

In this method we retained the rock of Method V and eliminated the heat up/cool down intervals of Method IV. With the rock (damper) separating the container from the heat, the kernels were burnt continuously and the extrusion rate increased to 25% as compared to 17% in Method V. Method VI demonstrates that the factors critical to reducing endosperm extrusion are both distance (temperature) and the heating up/cooling down of the plant remains.
Because of the increased extrusion rate, Method VI was not considered optimal. From these experiments we choose Method V to use on our Andean samples because it was the most replicative of archaeological maize.

Cupules were also tested using these methods, with the following results. Method IV produces cupules whose appearance is similar to cupules charred by Method V. Cupules charred using the continuous burning of Method III can withstand a higher temperature than kernels but they are more substantial and less fragile charred at the lower temperatures of Methods IV and V.

THE CHARRING PROCESS

All kernels and cupules from the six Andean types were charred using Method V. This method produced the least morphological distortion, thus yielding charred fragments that closely resemble archaeological maize. All sample kernels from each ear were charred together, one ear at a time, thereby subjecting all kernels from each ear to the same sets of conditions. This proceedure was also applied to cupules. The results of Method V, applied to kernels, are given in Table 2. Using 1 1/2 - 2 hour burning intervals, Method V took an average of 16 hours burning time to char one sample of kernels, with a minimum cooling time of 1/2 hour between each burning interval. The differences in burning time, may be due to differences in kernel size, endosperm composition, or a combination of both these factors. No simple correlation between sample size and length of burn time was found. For example, San Geronimo (SG2), a large kerneled flour, with a sample size of 36, took the longest time to burn; 20 hours. While Chullpi (C2), a long narrow sweet corn, with a sample size of 42, took 12 hours. Cupules were charred on the cob using Method V. Charring time was 10-12 hours per cob. After charring, individual cupules were removed from the cob with a tweezers and most cupules separated readily from the cob.[4]

The success of Method V challenges a commonly held assumption that "Such [archaeological] carbonization seems to require an extremely specific set of conditions which must have tremendously reduced the amount of maize that has been preserved in archaeological sites," (King 1986: 134). If this assumption were true, it would only be rare or unusual situations that resulted in preserved maize. From these experiments, we believe the opposite to be true. We speculate that, at least for the Peruvian Andes, where fuel resources are scarce and cooking fires burn for brief periods of time, (Johannessen and Hastorf, 1990) the repeated heating and cooling of the hearth would have been enough to char maize in the form we see it today. Therefore, our procedure, represented by Method V, could be very typical in a prehistoric setting. We also know from Method VI, that with low heat and enough distance from the heat source, maize will char when burned continuously. Method II (burning whole ears), and Method III (continuous burning), demonstrate that even under conditions less controlled than a hearth the potential exists for the survival of maize kernels and cupules. Further, both cupules and kernels left to burn after they have been fully charred retain their integrity. They do not disintegrate, crumble, or become more fragile. Therefore, charred maize subjected to additional heating is also likely to have survived archaeologically.

RESULTS OF MAIZE MEASUREMENTS

Our analysis included four assessments based on measurements for each of the six maize varieties. They were:

1) Distortion by variety: we defined the change in kernel and cupule shape and size by comparing measurements before and after charring. Included are direct and ratio measurements.

2) Distortion by endosperm type: we compared the direction and amount of distortion across endosperm types.

3) Evaluation of the measurements: from the distortion analysis, we determined which measurements are more reliable in the reconstruction of size and shape.

4) Row number and angle: we assessed the accuracy of predicting row number from kernel and cupule angle measurements.

Percentile box-plots, illustrated in Figures 6 - 9, provide a visual description of the multivariate pattern characterizing both the charred and uncharred kernels and cupules of each variety. At a glance we can see the median and the range of variation in a number of variables and therefore are able to compare similarities amd differences between kernel or cupule assemblages. Figure 10 displays the variability and distortion due to charring for all ears by comparing charred to uncharred kernel and cupule measurements.

Kernel Distortion - Changes in Shape and Size

Generally, with charring, we found that maize kernels become shorter, wider, and thicker with charring and that the change in cap type tends toward round. Change in kernel shape was determined by taking the mean of each measurement for each variety of unburnt specimens and comparing it to the mean of each measurement for the same sets of specimens once charred. Overall change in shape for kernels consists of a 5.5% decrease in length, 1.2% increase in width, and a 12.5% increase in thickness. These findings differ from previous experiments using parched maize (Fecteau 1985, King 1987, Pearsall 1980), where it was reported that all three dimensions increased. In our study the decrease in length ranged from 4.3% for Morocho to 8.8% for variegated. The increase in width ranged from 0.8% for San Geronimo to 3.6% for Morocho. The increase in thickness ranged from 5.1% for variegated to 20.6% for Cuzco Morado. Table 3 shows the mean for all measurements for each variety. Additionally, there was an overall increase in kernel angle of 1.6 degrees, which represents an increase of 5.5%. This modification of kernel angle (Bohrer 1986) was much less than we had anticipated. The increase in angle, by variety, ranged from 6^{o} for San Geronimo to less than 1^{o} for Chullpi. In general, the flour varieties had the largest increase in angle. Overall change in cap type is illustrated in Figure 4. We found that 7.9% of the square cap types and 6.3% of the beaked types become round with charring.

Ratios - Before and After Charring

Since kernel ratios describe the shape of the kernel, (see measurement discussion) many researchers have found kernel ratios to be an important diagnostic tool. Johannessen et al. (~~1989~~ n.d.) found the ratios of width/length and width/thickness to be among the most important kernel measurements when distinguishing maize types from one another. Pearsall (1980:349) uses width/length and width/thickness ratios to discuss kernel configuration as an aid in determining the "racial identity of archaeological maize." Our study measured the changes in ratio between charred and uncharred kernels, given in Table 6 by variety. When considering width/length ratio, a smaller number indicates slender kernels and a larger number is a more squat kernel. In our study, width/length ratio ranged from .557 for Confite and .926 for Cuzco. If the width/thickness ratio is 1, then width equals thickness. Therefore, if width/thickness is greater than 1, the kernel is wider than it is thick. At a ratio of 2/1 the kernel is twice as wide as it is thick. Our width/thickness ratio ranged from 1.1 for Confite to 1.6 for Cuzco.

Cupule Distortion - Changes in Shape and Size

Generally, we found that cupule height, depth, and width decrease while the center and wing lengths increase with charring. Overall change in cupule shape consists of a 8.1% decrease in height, a 29.8% decrease in depth, a 9.7% decrease in width, a 30% increase in center length, and a 15.7% increase in wing length. Table 4 contains the mean measurements for cupules by variety. Note that while the direction of change for cupules was consistent for all varieties the range of change was tremendous. For example, the increase in center length ranged from 9.6% for Confite to 57.8% for the variegated variety. One explanation for this wide range of change is the large, naturally occuring range of variability found in cupule shape. Figure 3 illustrates this variability. Change in cupule angle could not be determined because we were unable to measure the angle of uncharred cupules. (See previous discussion on measurements.)

The cupule data, unlike the kernel data, cannot provide a meaningful reconstrution formula because the range of change among cupule varieties was tremendous. However, cupule data from our study revealed two interesting findings. First, unlike all other cupule measurements, width decreased uniformly across varieties (Table 4). Second, when we investigated the relationship between angle and row number, we found that the angle measurement from charred cupules was a better predictor of row number than either charred or uncharred kernels. These relationships are displayed in scattergrams illustrated in Figure 5. A correlation and regression analysis performed on the data from these scattergrams produced a ~~correlation~~ of determination co-efficient, R-squared, of .372 for uncharred kernels, .531 for charred kernels, and .653 for charred cupules. For charred cupules 63.5% of the variability in cupule angle is accounted for by the expected angle. In other words, 63.5% of the variability in the measured angles of charred cupules ~~corresponded to~~ can be accounted for by their expected angle, as opposed to 53.1% for charred kernels. Given these findings, it is not surprising that Bird and Bird (1980), Bird and Dobbs (1990) [check date], and Johannessen et al. (n.d.), found that cupule width and angle were the most important measurements in distinguishing maize types, using cupules.

Kernel Measurements

King (1987) recommends one additional measurement for kernels. A second length measurement, defined as sub-length, (Fig. 2) would indicate the distance from the base of the kernel to the point at which you take the width measurement. This measurement would show the length of maximum width above the base and may reveal what section of the kernel gets shorter during charring, thereby explaining the observed change in kernel angle. Unfortunately, we did not use

also helps a lot to describe the shape, e.g. vs. Would separate these two types.

this measurement in the study because had we assumed length would increase with charring as it had done for King (1987), and Pearsall (1980).

Cupule Measurements

Cupule shape is too complex to be described in a few measurements. An additional measurement, defined as end length, (Fig. 2) that describes the total length of the cupule from front to back across the top, creates the potential for additional analysis. Adding this measurement would clarify the shape of the cupule from center length to wing length. We recommend discontinuing the depth measurement (Fig. 2) since, like King (1987), we found it to be unreliable because of the difficulty in taking a depth measurement off the cob; a necessity when examining archaeological maize.

Effect of Endosperm Type on Charring

We examined changes due to charring for both kernels and cupules, looking for a relationship between endosperm type and amount of change. Table 5 indicates the percent of change due to charring, organized by variety and endosperm type. The percent of change varied widely, in particular among the flours, with a 5.1% increase in thickness for variegated kernels to a 20.6% increase for Cuzco kernels. Examination of Table 5 shows that endosperm type is not a simple predictor of change for either kernels or cupules. However, there is a relationship between endosperm type and overall cupule size. Using volume, by applying the formula; width x length x height, we compared the size of charred cupules by variety. We found, like Galinat (1970), that cupule size becomes progressively smaller based on endosperm type, going from the largest, flour to flint to sweet ending with popcorn, the smallest.

→ I don't think this makes sense, because the endosperm types do not fall into any particular natural order.

Using Angle to Predict Row Number

Methods for determining kernel angle range from cardboard measuring devices, (Pearsall 1980), to photocopiers, (King 1987), to the use of microscopes and graph paper as in this study. What should be noted, however, is that even with the subjectivity inherent in taking angle measurements, all these methods have produced similar results. First, that taken by itself, the angle of any one kernel when predicting row number has a low to medium rate of accuracy. The R-squared value for uncharred kernels is .372 and for charred kernels is .531, (see Distortion section). Second, our kernel angle data sorted into two groups, low row number (8-10) and high row number (12-16). Table 7 compares the actual and apparent row number of charred kernels and cupules, given in percent, where the apparent row number is calculated from the angle measurement. (The measurement section of this paper describes how to work with angle and row number.) 62.1% of the kernels from 8-rowed cobs had an apparent row number of 8, 46.3% of the kernels from 10-rowed cobs had an apparent row number of 10 and 45.7% of the kernels from 12-rowed cobs had an apparent row number of 12.

While our kernel angle data tended to separate into two groups, these groups overlap to some degree. We felt a more accurate picture of the relationship of angle to row number would be one that examines both grouping and overlap, as shown in Table 8. This table organizes angle data, by count, comparing actual and apparent row number. While knowing kernel angle will not tell you the correct row number in all cases it will tell you some of the possible row numbers the kernel will not be. We found that if you have an angle reading for charred kernels that translates into an apparent[5] row number of 14 or above, you know that the kernel did not come from an ear of less than 10 rows.

If you have a translated angle reading of 8 rows or less, you know that kernel did not come from an ear of more than 10 rows. Further, if you use the angle information in conjunction with the kernel's ratio configuration, (Pearsall 1980), and with the added information about distortion provided by this study we believe that it is possible to reconstruct the shape and size of archaeological kernels and solidly approach the question of maize varieties in the archaeological record.

Cupule Angle

Angle measurements for cupules, like kernels, sort into overlapping groups. Percentages for this data are found in Table 7. The apparent row number calculated from cupule angle measurements is given in Table 8. The cupule groupings indicate that if you have an angle reading that translates into an apparent row number of 16 or above, you know that the cupule did not come from an ear of less than 12 rows. If you have a translated angle reading of 10, rows you know that the cupule came from an ear of no more than 14 rows. If you have an angle representing 8 rows, you know it came from an ear of no more than 10 rows. Based on the correlation and regression analysis, we found that cupule angle is a more accurate predictor of row number than kernel angle. Cupule angle may be more accurate because cupule sides are flatter, producing a more accurate angle measurement, and because cupule angles are numerically farther apart than kernel angles. This idea is demonstrated in the mean comparison of expected vs. actual angle, given in Table 9, organized by ear.

DISSCUSSION AND CONCLUSIONS

Our purpose was to find techniques and measurements that may help interpret prehistoric maize remains as a source of information about human culture. We believe our work has strong implications for prehistoric charring conditions, along with insights into how maize entered the archaeological record. Additionally, since all the methods we attempted produced charred maize, albeit some better than others, we concluded that the potential exists for the archaeological survival of maize under a number of differing conditions.

The development of a charring method, which produces maize fragments closely resembling archaeological ones, indicates that the size and shape of prehistoric maize can be reconstructed. However, we believe that reconstructing the size and shape of kernels is more useful than cupules because of the highly variable cupule shape. As for cupules, our work confirms past research; that cupule width and angle are still the best diagnostic features for determining maize varieties. The reliability of width and angle was demonstrated in our findings: all cupules exhibited the same kinds of shape change when charred. Further, we believe that our study provides information on distortion, angle and ratio that will allow researchers to solidly approach the question of maize types, based on archaeological fragments. In turn, knowledge of maize types allows archaeologists to study maize as a cultural artifact contributing to the understanding of New World societies.

Mindful of the limitations imposed on researchers in time and resources, we hope to have made a contribution to the potential use of measurements in interpreting the archaeological record. We found that the measurements used in our study are easily replicated and are not so many as to be overwhelming. These measurements will define the differences between charred and uncharred maize and are useful comparisons to measurements taken by others engaged in the work of interpreting the archaeological record.

One of the unlooked for bonuses of this study was the data concerning the differences between the experimental and archaeological maize kernels. Experimental kernels retained their pericarp and embryo after charring, while among archaeological kernels the embryos are often missing as well as much of the pericarp. While experimental kernels appear to be good candidates for preservation, the differences between experimental and archaeological kernels are well worth noting. We believe that the loss of embryo and pericarp may be related to processing. Indigenous peoples of both North and South America use lye to process corn, (Grobman et al 1969, Gade 1975, and King 1987) which results in the removal of the embryo and the pericarp. Based on the differences between the experimental and archaeological kermels, it is our opinion that these differences demonstrate that you can see processing in the archaeological record. The results of this study have led us to develop another charring experiment using processed maize. These experiments have infused us with optimism about our attempts to derive information about human culture from prehistoric maize remains.

ACKNOWLEDGEMENTS

This research was funded by the National Science Foundation Research Experience for Undergraduates program (BNS 8451369), directed by Christine A. Hastorf and Sissel Johannessen. Valuable lab assistance was provided by Heidi Lennstrom. We thank Deborah Pearsall and Frances King for informal discussions as the study progressed.

1.Confite Puntiagudo was identified by a Peruvian woman in the market where it was collected. During the study, it was discovered that both ears of the popcorn type were not of the same variety: one was Confite Morocho (CP1), the other, Confite Puntiagudo, (CP2). It was not possible to make this distinctions until the kernels had been removed from the cob and the cupules examined. It was decided to continue the experiment using these ears, with the possibility of assessing differences between ears of closely related varieties.

2. The ratio of kernels to cupules in this study is 2:1. Since two kernels sit in a single cupule on an ear of maize, a cob with 8 rows of kernels has 4 rows of cupules.

3. Initially, a calibrated toothpick was used to measure cupule depth. The wooden tips would wear down and splinter with use, giving false readings. To solve this problem, a metal probe was calibrated and used for measuring depth.

4. Confite Morocho (CP1) cupules, were fragile after charring and therefore difficult to separate from the cob intact.

5. The apparent row number was determined by dividing 360 degrees by the measured angle of the kernel.

REFERENCES CITED

Benz, Bruce Measurements
1986 Taxonomy and Evolution of Mexican Maize. Ph.D. Dissertation, Department of Botany. University of Wisconsin - Madison.

Bird, Robert M. and J.B. Bird Measurements Cup < and width = type
1980 Gallinazo Maize from the Chicama Valley, Peru. <u>American Antiquity</u> 45: 325-332

Bird, Robert M. and Clark A. Dobbs Cup < and width = type
~~1990~~ 1986 Archaeological Maize From the Vosburg Site (21FA2), Faribaut County, Minnesota. <u>The Missouri Archaeologist</u> 47: 85-105.

• Bird, Robert M. and Major M. Goodman (Morocho Cupules) (Race = use)
1978 The races of Maize V: grouping maize races on the basis of ear morphology. <u>Economic Botony</u> 31: 471-481.

? Bird, Robert M. and T. E. Pickenpaugh
1980 Maize and the Brokaw Site. <u>Ohio Archaeology</u> 30 :31-33.

Bohrer, Vorsila L. Row # /< Ker ang
1986 Guideposts in ethnobotany. <u>Journal of Ethnobotany</u> 6(1): 27-43.

Cutler, Hugh C. 360°
1956 Plant remains. <u>In</u> P.S. Martin, J.B. Rinaldo, E.A. Bluhm, and H.C. Butler, Higgins Flat Pueblo, Western New Mexico. Fieldiana, Anthropology Series 45: 174-183.

Cutler, Hugh C. and Lenard Blake Row # < = type 360°
1973 Plants from Arch Sites East of the Rockies, University of Missouri-Columbia, American Archaeological Division, American Archaelogical Reports. No. 1 Microfiche.

Doebley, John and Vorsila L. Bohrer Endosperm characteristics
1983 Maize variability and cultural selection at Salmon Ruin, New Mexico. <u>The Kiva</u> 49 (1-2): 19-37.

Fecteau, R.D. size increase everywhere
1985 The introduction and diffusion of cultivated plants in Southern Ontario. Ms. Thesis, Department of Geography, York University, Toronto, Ontario.

Gade, Daniel W. Ethnographic
1975 Plants, man and the land in the Vilcanota Valley of Peru. Dr. W. Junk B.V., Publishers, The Hague.

Galinat, Walton C. Cupule size decrease
1970 The cupule and its role in the origin and evolution of maize. University of Massachusetts Agricultural Experimental Station 585 :1-12.

Goodman, Major M. and E. Paterniani Row # L = type
1969 The races of maize: III. Choices of appropriate characters for racial classification. Economic Botany 23: 265-273.

Grobman, A., D. Bonavia and D.H. Kelly, with P.C. Mangesdorf and J. Camara-Hernandez. ID of maize
1977 Study of pre-ceramic maize from Huarmey, north central coast of Peru. Botanical Museum leaflets of Harvard University 25: 221-242.

Johannessen, Sissel, S. Goette, and C.A. Hastorf. Ratios cup L width = type
n.d. Modern and Ancient Maize Fragments: An Experiment in Variability. University of Minnesota. Journal of Quantitative Anthropology, in review.

Johannessen, Sissel and C.A. Hastorf Fuel use
1990 History of Fuel Management (A.D. 500 to the present) in the Mantaro Valley, Peru. Journal of Ethnobiology.

King, Francis Experiments Row # /L Ratios arch characteristics
1987 Prehistoric maize in Eastern North America; an evolutioary evaluation. Ph.D. dissertation, Department of Agronomy, University of Illinois-Urbana. discontinue depth add sub-length

Miksicek, Charles H., McK. Bird, B. Pickersgill, S. Donaghey, J. Cartwright, and N. Hammond. Measurement
1981 Preclassic lowland maize from Cuello, Belize. Nature 289: 56-59.

Nickerson 1953 measurements

Pearsall, Debbie Experiments - Row # /L Ratios
1980 Analysis of an Archaeological Maize Cache from Manabi Province Ecador.

Purseglove, J. W. (Endosperm definition)
1972 Tropical Crops: Monocotyledons, Longman Group Limited, London.

ACKNOWLEDGEMENTS

This research was funded by the National Science Foundation Research Experience for Undergraduates program (BNS 8451369), directed by Christine A. Hastorf and Sissel Johannessen. Valuable lab assistance was provided by Heidi Lennstrom. We thank Deborah Pearsall and Frances King for informal discussions as the study progressed.

TABLES

SAMPLE DATA

Table 1

MAIZE	EAR CODE	ROW NUMBER	TYPE	LOCATION COLLECTED	KERNEL COUNT	CUPULE COUNT
Confite Morocho	CP1	12	pop	Jauja '82	36	18
Confite Puntiagudo	CP2	16	pop	Jauja '82	58	29
Chullpi	C1	16	sugar	Huancayo '82	42	21
Chullpi	C1	14	sugar	Huancayo '82	42	21
Morocho	M1	10	flint	Ayacucho '80	26	13
Morocho	M2	8-10	flint	Ayacucho '80	38	19
Cuzco Morado	CM1	8	flour	Jauja '82	29	16
Cuzco Morado	CM2	10	flour	Jauja '82	44	22
San Geronimo-	SG1	10	flour	Ayacucho '80	36	18
Huancavelicaño	SG2	10	flour	Ayacucho '80	36	18
Variegated	VER1	10	flour	Jauja '79	24	12
Variegated	VER2	8-10	flour	Jauja '79	30	15
Total					441	221

Table 2

CHARRED KERNELS
RESULTS OF METHOD V

RACE/TYPE	EAR	n	BURN TIME HOURS:	EXTRUSION RATE Count	EXTRUSION RATE Percent
Confite Morocho	CP1	36	13	6	16.6
Confite Puntiagudo	CP2	58	16	14	24.1
Chullpi	C1	42	14	9	21.4
CHullpi	C2	42	12	0	0
Morocho	M1	26	16	8	30.7
Morocho	M2	38	18	9	23.6
Cuzco Morado	CM1	29	14	4	13.8
Cuzco Morado	CM2	44	16	8	18.2
San Geronimo-Huancavelicaño	SG1	36	18	10	27.7
	SG2	36	20	5	13.8
Variegated	VER1	24	16	0	0
Variegated	VER2	30	16	2	6.7

Average extrusion rate for all kernels is 16.5%

Table 3

EFFECTS OF CHARRING
KERNELS

	All Ears n=443		Confite n=94		Chullpi n=84		Morocho n=64		Cuzco Morado n=74		San Ger n=72		Variegated n=54		Range of Change %
	unchar	char	unchar	char	unchar	char	unchar	char	unchar	char	unchar	char	unchar	char	
Length	1.164	1.1	.982	.968	1.258	1.163	1.165	1.122	1.157	1.105	1.238	1.154	1.243	1.133	1.43 - 8.84
change cm	.064		.014		.095		.043		.052		.084		.110		
% change	5.50		1.43		7.55		3.69		4.49		6.79		8.84		
Width	.82	.83	.579	.577	.742	.757	.915	.948	1.003	1.003	.885	.892	.916	.910	0.35 - 3.61
change cm	.01		-.002		.015		.033		.013		.007		-.006		
% change	1.22		.35		2.02		3.61		1.30		.79		.62		
Thickness	.599	.674	.470	.519	.536	.606	.716	.839	.539	.65	.673	.74	.769	.808	5.07 - 20.59
change cm	.075		.049		.070		.123		.111		.067		.039		
% change	12.52		10.43		13.06		17.18		20.59		9.96		5.07		
Angle	29.31	30.93	22.55	21.93	21.824	22.176	34.746	37.063	43.22	42.40	28.68	34.77	28.98	34.74	1.61 - 13.42
change degree	1.62		-.62		.352		2.317		-.82		6.09		3.89		6.67
% change	5.53		2.75		1.61		6.67		1.90		21.23		13.42		

Table 4

EFFECTS OF CHARRING
CUPULES

	All Ears n=221 unchar	All Ears char	Confite n=47 unchar	Confite char	Chullpi n=42 unchar	Chullpi char	Morocho n=32 unchar	Morocho char	Cuzco Morado n=37 unchar	Cuzco Morado char	San Ger n=36 unchar	San Ger char	Variegated n=27 unchar	Variegated char	Range of Change %
Height	.307	.282	.25	.265	.331	.301	.33	.281	.341	.299	.299	.261	.32	.287	6.0 - 14.85
change cm	.025		+.015		.03		.049		.042		.038		.033		
% change	8.14		6.00		9.06		14.85		12.32		12.71		10.316		
Width	.693	.626	.498	.42	.552	.587	.778	.673	.914	.835	.715	.593	.819	.75	6.34 - 17.06
change cm	.067		.078		.035		.105		.079		.122		.069		
% change	9.67		15.66		6.34		13.50		8.64		17.06		8.42		
Depth	.151	.105	.117	.072	.189	.089	.187	.153	.15	.116	.124	.119	.141	.1	4.03 - 52.91
change cm	.046		.045		.1		.034		.034		.005		.041		
% change	30.46		38.46		52.91		18.18		22.67		4.03		29.08		
Center Length	.178	.225	.167	.183	.145	.21	.223	.256	.197	.243	.191	.242	.154	.243	9.58 - 57.79
change cm	.047		.016		.065		.033		.046		.051		.089		
% change	26.40		9.58		44.83		14.80		23.35		26.70		57.79		
Wing Length	.274	.317	.249	.273	.215	.31	.281	.322	.33	.332	.327	.336	.257	.352	0.61 - 44.19
change cm	.043		.024		.095		.041		.002		.009		.095		
% change	15.69		9.64		44.19		14.59		0.61		2.75		36.96		

What about pluses & minuses? I thought height decreased!

Table 5

ENDOSPERM COMPOSITION
PERCENT OF CHANGE DUE TO CHARRING

KERNELS

ENDOSPERM:	Pop	Sweet	Flint		Flour	
VARIETY:	Confite	Chullpi	Morocho	Cuzco	San Geronimo	Variegated
n:	94	84	64	73	72	54
Height	1.43	7.55	3.69	4.49	6.79	8.84
Width	-.35	2.02	3.61	1.30	.79	.66
Thickness	10.43	13.06	17.18	20.59	9.96	5.07

CUPULES

ENDOSPERM:	Pop	Sweet	Flint		Flour	
VARIETY	Confite	Chullpi	Morocho	Cuzco	San Geronimo	Variegated
n:	47	42	32	37	36	27
Height	+6.0	9.06	14.85	12.32	12.70	10.31
Width	15.66	6.34	13.50	8.64	17.06	8.42
Center Length	9.58	44.83	14.80	23.35	26.70	57.79

Table 6

CHANGE IN KERNEL RATIO DUE TO CHARRING

WIDTH/LENGTH RATIO				WIDTH/THICKNESS RATIO			
	Unchar	Char	Change		Unchar	Char	Change
Confite	.590	.557	.007	Confite	1.254	1.126	.128
Chullpi	.601	.665	.064	Variegated	1.217	1.141	.076
San Geronimo	.718	.782	.064	Morocho	1.310	1.141	.169
Variegated	.747	.814	.067	San Geronimo	1.351	1.223	.128
Morocho	.790	.849	.059	Chullpi	1.449	1.281	.168
Cuzco	.873	.926	.053	Cuzco	1.899	1.607	.292
All Ears	.708	.757	.049	All Ears	1.419	1.252	.163

Smaller w/L ratio are most slender kernels, larger w/L are more squat kernels. With charring, width increases as height decreases, therefore positive change. The larger the w/t ratio, the wider the kernel relative to thickness. With charring, thickness increases at a greater rate than width increases, therefore w/t change is negative.

Table 7

ACTUAL VERSUS APPARENT ROW NUMBER

Calculated From Angle Measurement
Given As A Percent

CHARRED KERNELS

ACTUAL ROW NUMBER	n	APPARENT ROW NUMBER <6	8	10	12	14	16	>16
8	29	10.3	62.1	24.1	*			
8-10	67		28.4	37.3	16.4	11.9	6.0	
10	160	*	15.6	46.3	23.8	8.8	4.4	*
12	35				45.7	28.6	20.0	5.7
14	42			*	9.5	19.0	47.6	21.4
16	100			3.0	10.0	11.0	60.0	16.0

CHARRED CUPULES

ACTUAL ROW NUMBER	n	APPARENT ROW NUMBER <6	8	10	12	14	16	>16
8	15	13.3	53.3	20.0	13.3			
8-10	34		11.8	52.9	29.4	5.9		
10	83		19.3	47.0	27.7	7.2	*	
12	18			*	22.2	38.9	16.7	16.7
14	21			*	28.6	23.8	14.3	28.6
16	50				*	24.0	22.0	52.0

* indicates a single kernel or cupule

Table 8

APPARENT ROW NUMBER CALCULATED FROM ANGLE
GIVEN AS A COUNT

UNCHARRED KERNELS

TYPE OF COB	ACTUAL ROW #	n	APPARENT ROW NUMBER <6	7	8	9	10	12	14	16	18	>18
CM1	8	29	11	6	6	3	2	1				
M2	8-10	34		2	6	5	8	3	5	2	3	
VER2	8-10	28			2	2	3	9	4	6	1	1
SG1	10	36			2	4	7	6	5	7	3	2
SG2	10	36				7	4	12	6	5	2	
VER1	10	24				4	6	4	3	5	2	
M1	10	25		1	2	8	7	4	3			
CM2	10	44	4	4	7	12	8	6	3			
CP1	12	36						16	17	3		
C2	14	42					2	8	13	12	6	1
C1	16	42					1	2	7	18	11	3
CP2	16	58							12	33	13	

CHARRED KERNELS

TYPE OF COB	ACTUAL ROW #	n	APPARENT ROW NUMBER <6	7	8	9	10	12	14	16	18	>18
CM1	8	29	3	14	4	6	1	1				
M2	8-10	37		9	5	9	6	4	3	1		
VER2	8-10	30			5	9	1	7	5	3		
SG1	10	30			4	7	11	7		1		
SG2	10	36			3	7	10	11	5			
VER1	10	24		1		6	5	3	6	2	1	
M1	10	26		2	3	4	4	7	2	4		
CM2	10	44	1	5	7	19	1	10	1			
CP1	12	35							16	10	7	2
C2	14	42					1	4	8	20	8	1
C1	16	42					3	10	4	20	5	
CP2	16	58							7	40	11	

CHARRED CUPULES

TYPE OF COB	ACTUAL ROW #	n	APPARENT ROW NUMBER <6	7	8	9	10	12	14	16	18	>18
CM1	8	15	2	4	4	2	1	2				
M2	8-10	19			1	2	10	5	1			
VER2	8-10	15		1	2		6	5	1			
SG1	10	18			1	1	11	5				
VER1	10	12			2	3	4	3				
M1	10	13				1	6	4	2			
CM2	10	22		2	10	3	2	5				
CP1	12	18					1	4	7	3	3	
C2	14	21					1	6	5	3	6	
C1	16	21							6	4	7	4
CP2	16	29						1	6	7	12	3

Table 9

MEAN ANGLES: EXPECTED AND MEASURED
GIVEN IN DEGREES

TYPE BY EAR	ACTUAL ROW #	KERNEL ANGLE EXPECTED	KERNEL ANGLE MEASURED	CUPULE ANGLE EXPECTED	CUPULE ANGLE MEASURED
CONFITE					
CP1	12	30	28.6	60	51.9
CP2	16	22.5	19.9	45	42.0
CHULLPI					
C1	16	22.5	20.4	45	41.4
C2	14	25.7	23.2	51.4	50.7
MOROCHO					
M1	10	36	36.0	72	66.9
M2	8-10	36-45	33.8	72-90	71.5
CUZCO MORADO					
CM1	8	45	48.4	90	88.6
CM2	10	36	39.7	72	81.5
SAN GERONIMO					
SG1	10	36	27.9	72	65.6
SG2	10	36	29.4	72	71.1
VARIEGATED					
VER1	10	36	29.8	72	75.4
VER2	8-10	36-45	29.0	60-72	73.3

FIGURE 1

Maize Types Used in this Study

A = Confite Puntiagudo

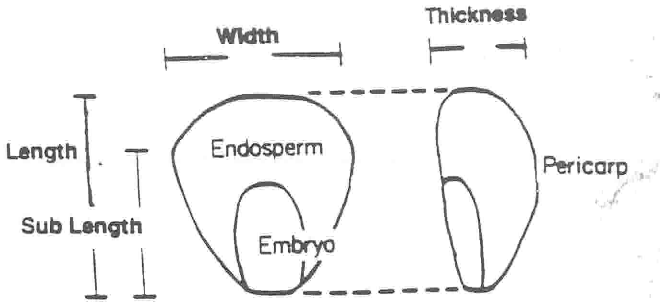
B = Chullpi

C = Variegated

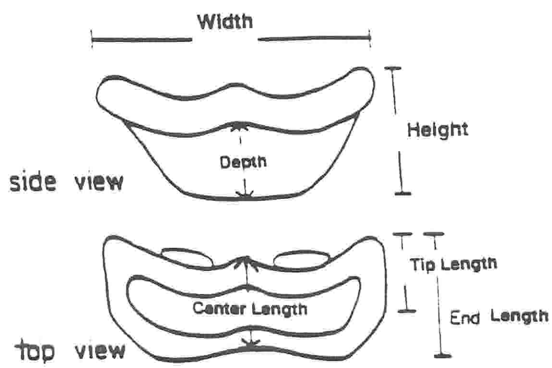
D = San Geronimo-Huancavicaño

E = Morocho

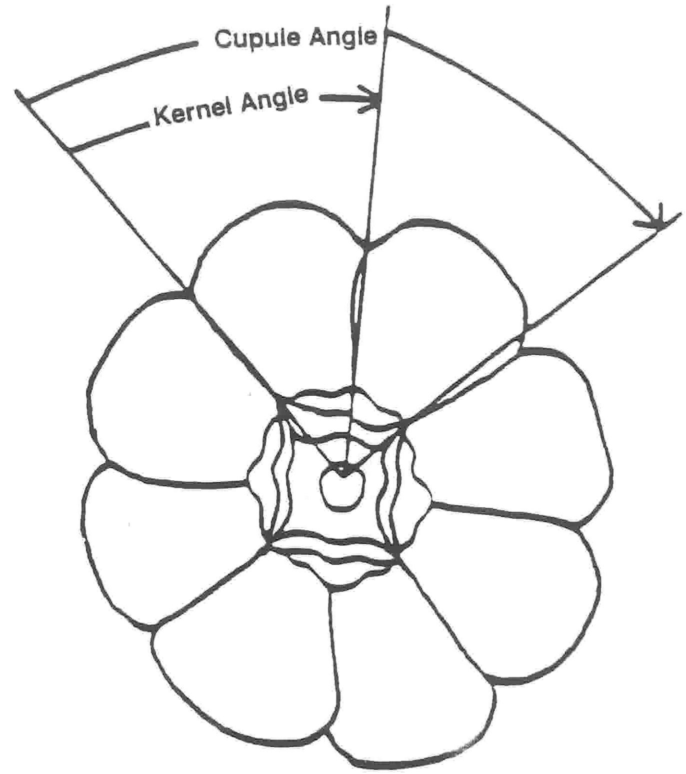
F = Cuzco Morado



KERNEL

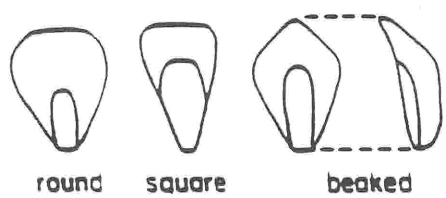


CUPULE



Cross section of maize ear*

*Adapted from Benz 1986:44



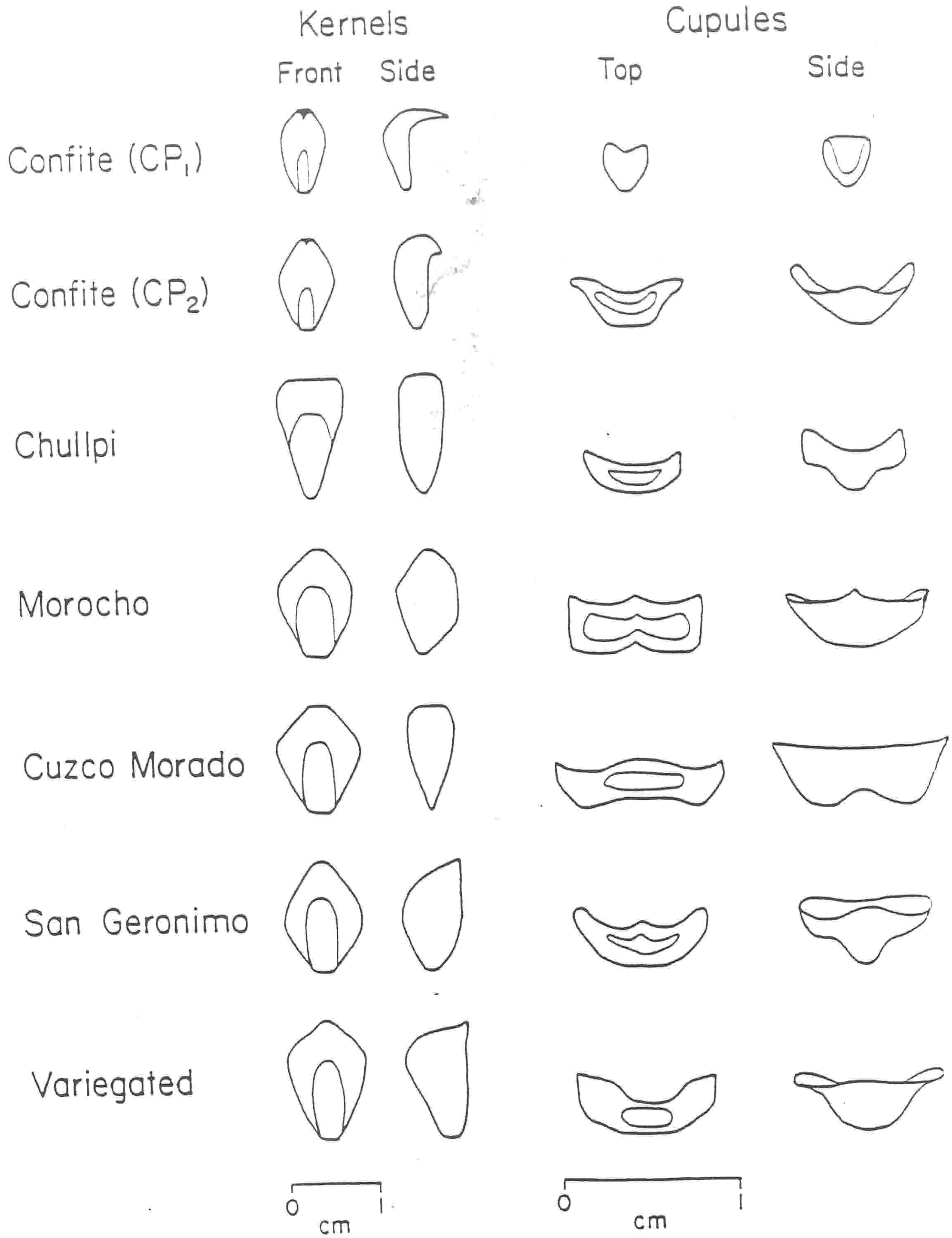
Cap types

$$\text{Row number} = \frac{360°}{\text{Kernel angle}}$$

$$\text{or} \quad \frac{360°}{\text{cupule angle}} \times 2$$

MEASUREMENTS

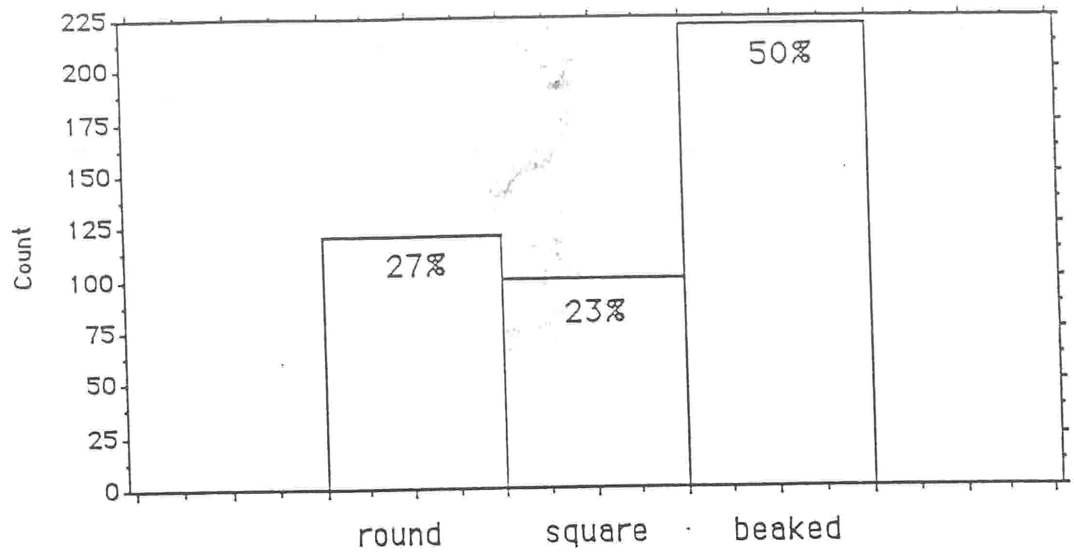
FIGURE 2



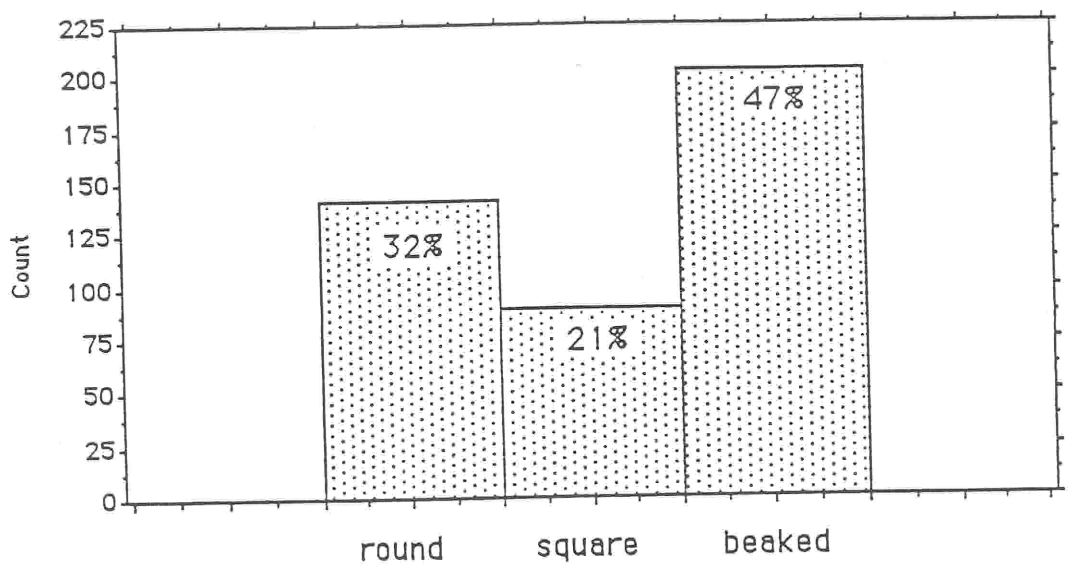
See Appendix for mean measurements used to reconstruct shape

Typical Kernel and Cupule Shape and Size

FIGURE 3



uncharred

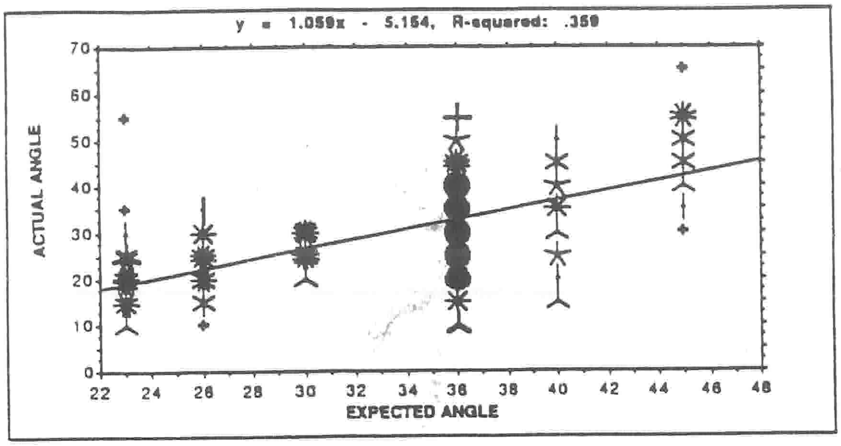


charred

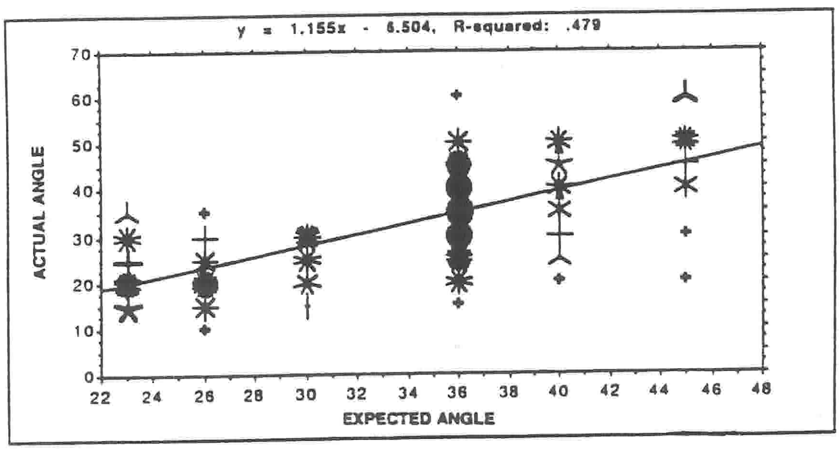
Change in Cap Type

FIGURE 4

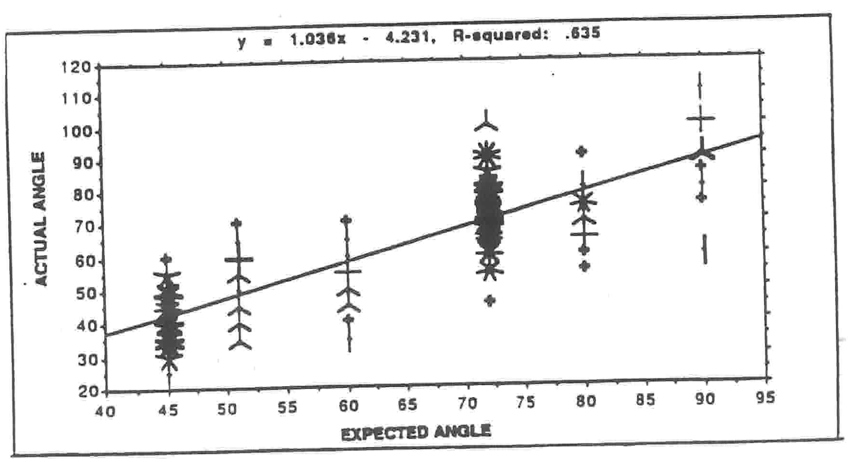
UNBURNT KERNEL



BURNT KERNEL

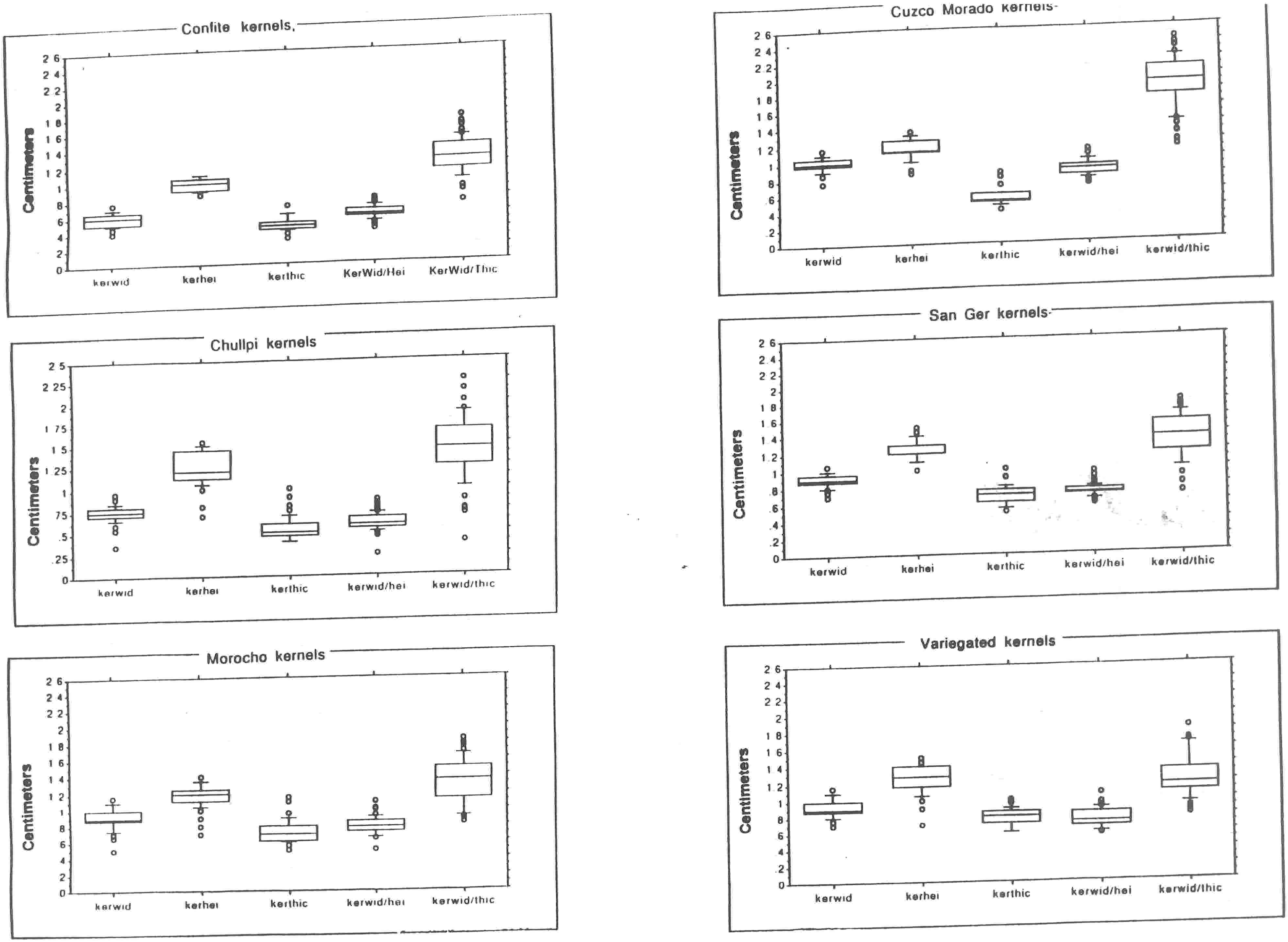


BURNT CUPULE



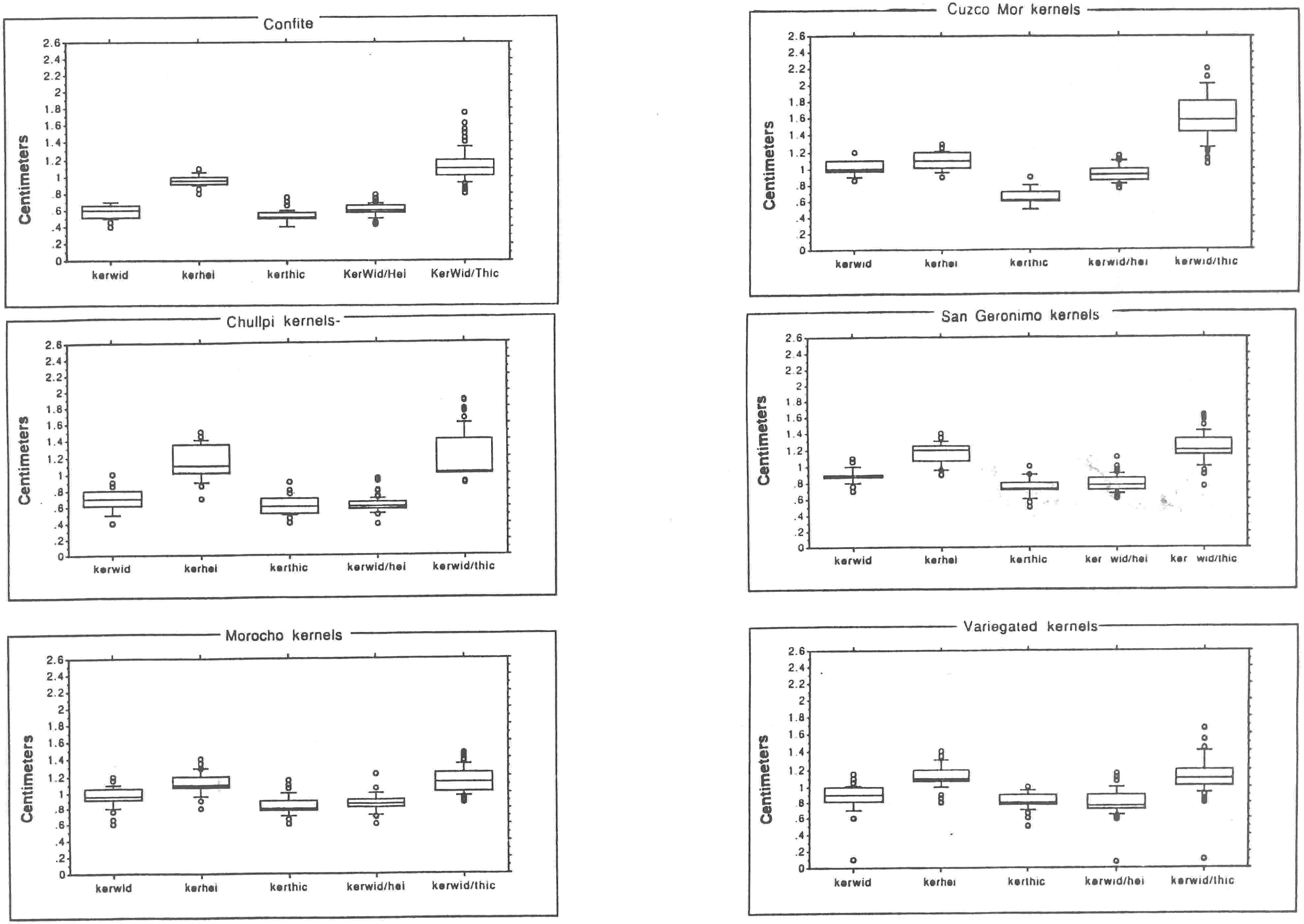
ACTUAL ANGLE VS EXPECTED ANGLE

FIGURE 5



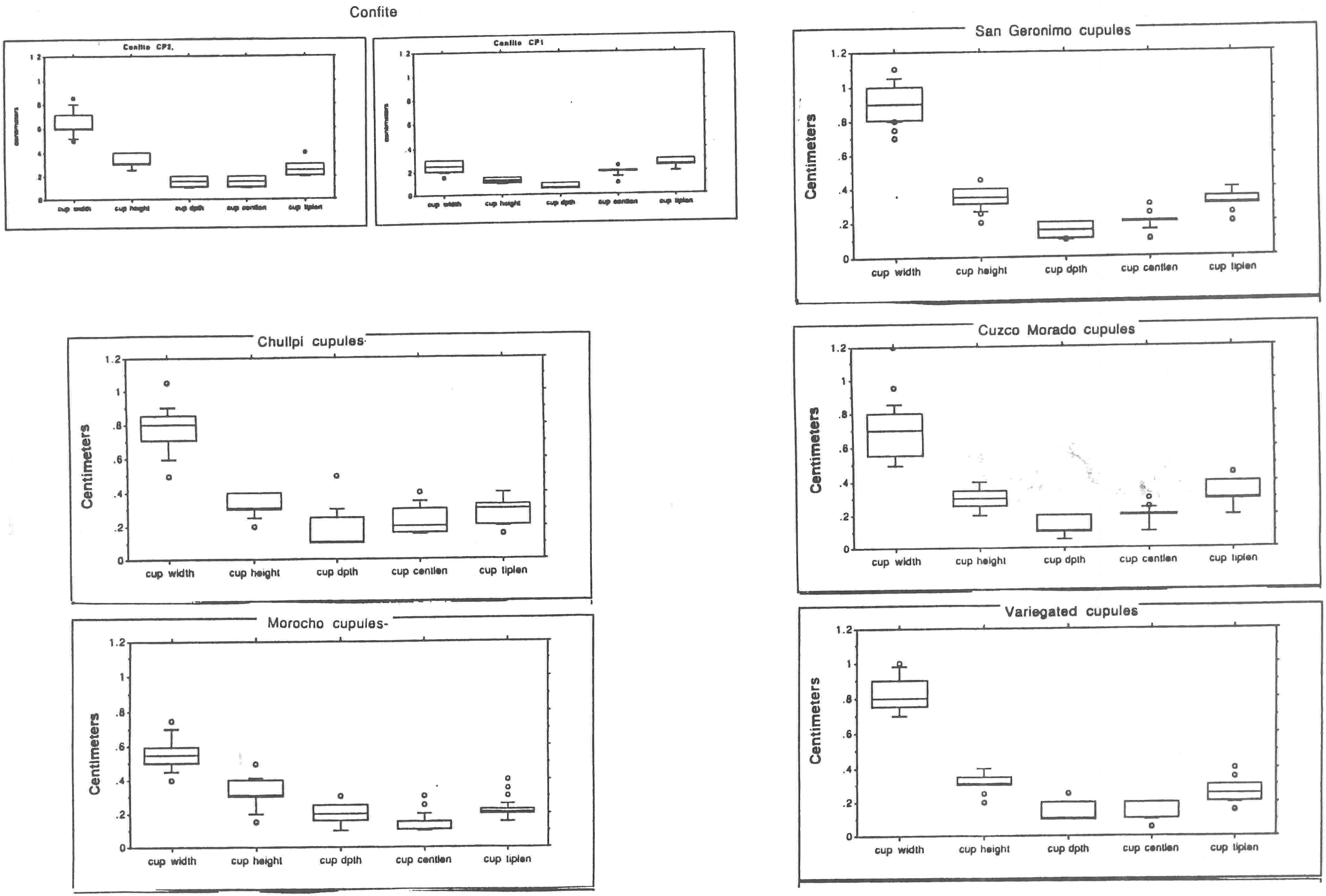
Kernel Variability by Variety, uncharred

FIGURE 6



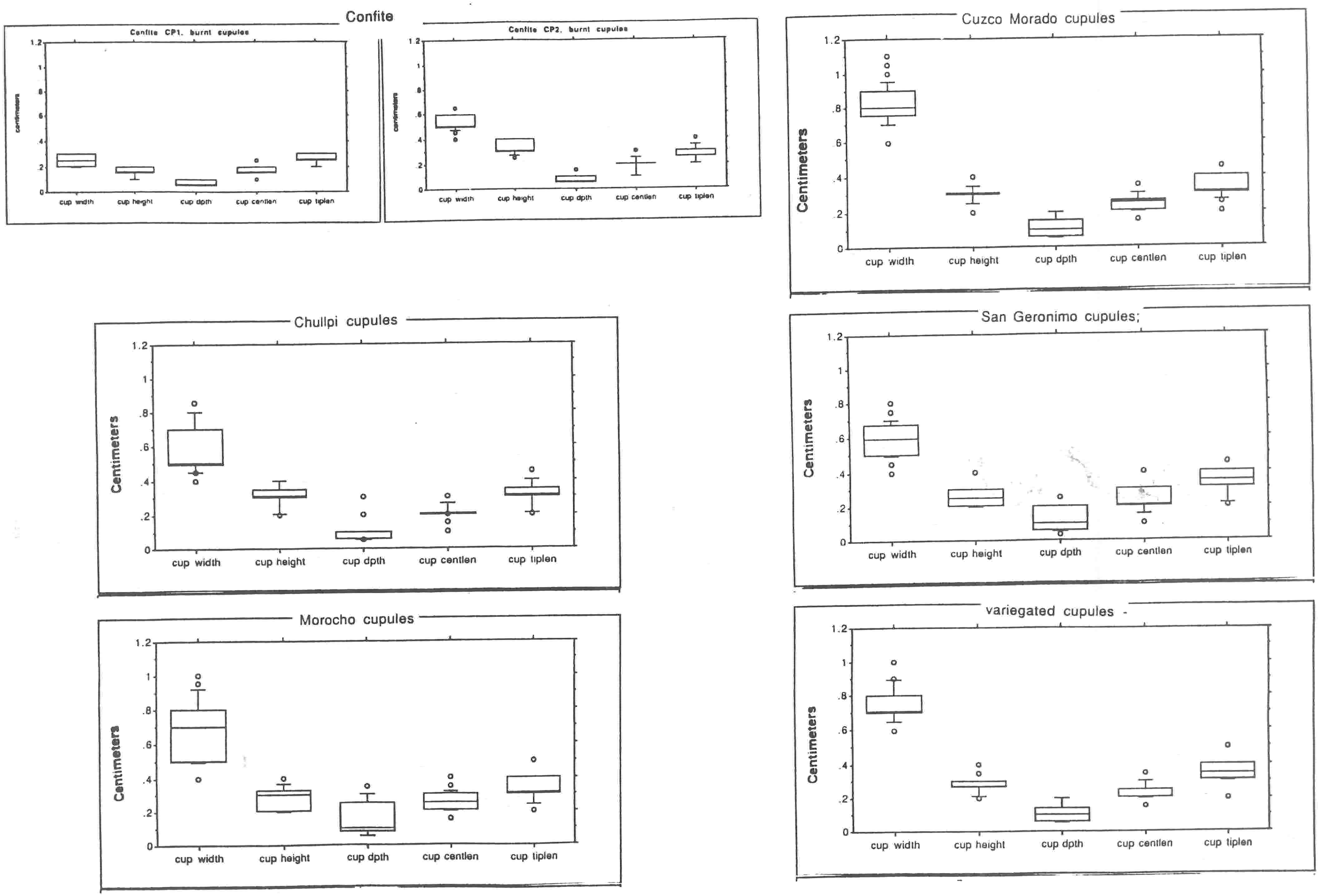
Kernel Variability by Variety, charred

FIGURE 7



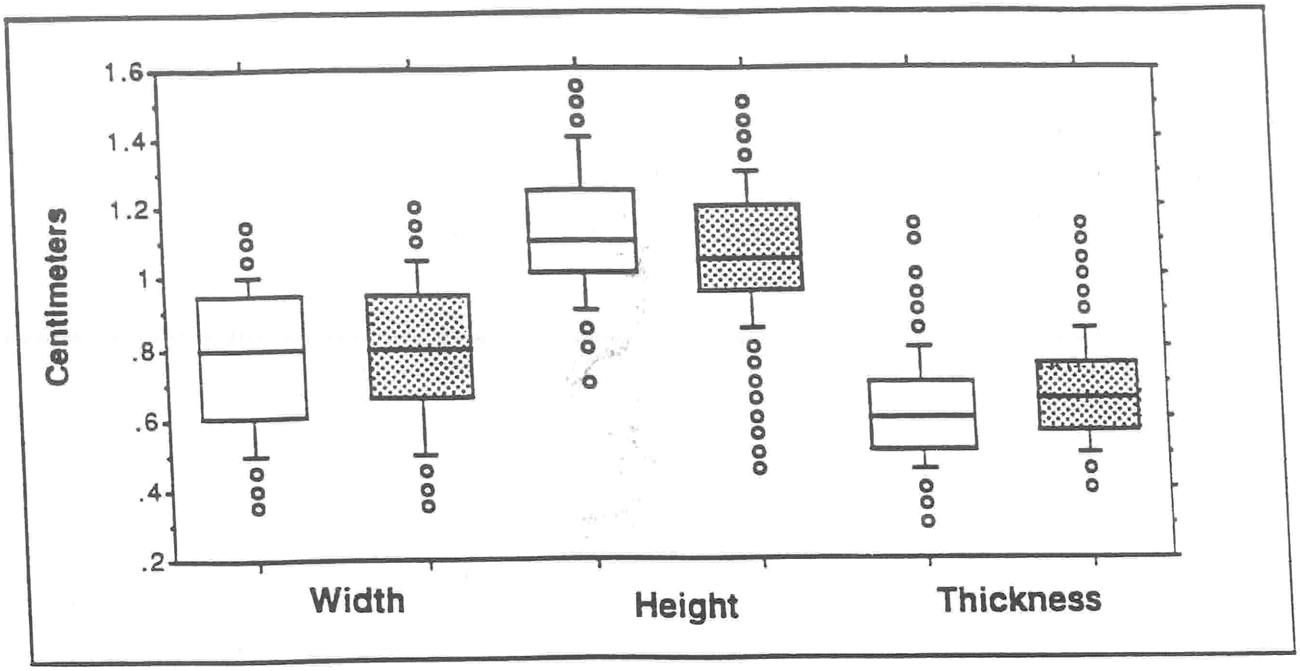
Cupule Variability by Variety, uncharred

FIGURE 8

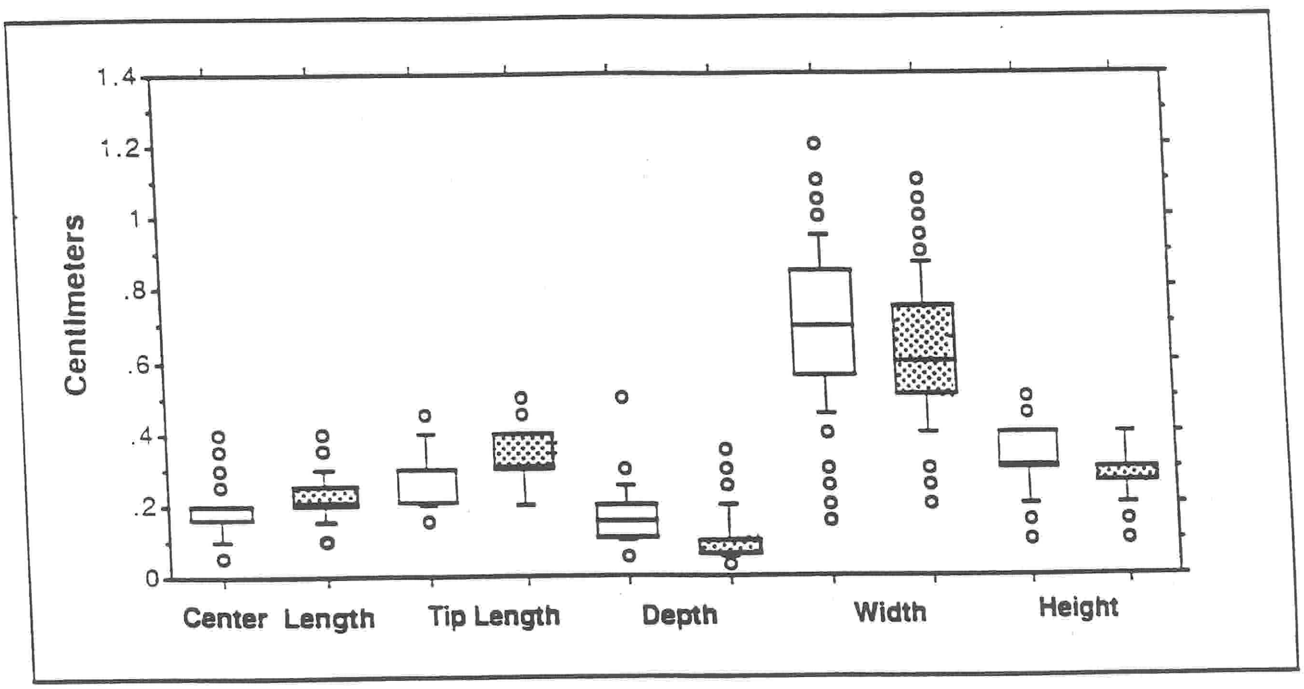


Cupule Variability by Variety, charred

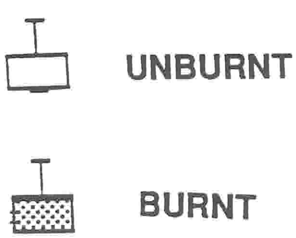
FIGURE 9



KERNEL DISTORTION DUE TO CHARRING



CUPULE DISTORTION DUE TO CHARRING



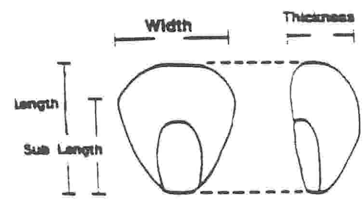
Variability of All Ears Combined

FIGURE 10

APPENDIX
Mean Measurements

KERNELS

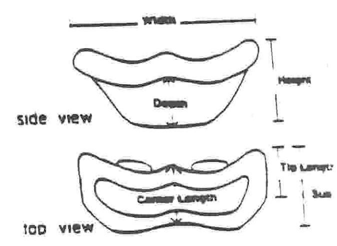
	Width	Height	Thickness
Confite 1	.50	.90	.40
Confite 2	.60	1.00	.50
Chullpi	.75	1.25	.50
Morocho	.90	1.15	.70
Cuzco	1.00	1.15	.50
San Geronimo	.90	1.20	.70
Variegated	.90	1.25	.75



KERNEL

CUPULES

	Width	Length	Thickness	Height	Depth
Confite 1	.125	.20	.25	.125	.50
Confite 2	.65	.15	.25	.35	.20
Chullpi	.55	.15	.20	.35	.20
Morocho	.80	.25	.30	.35	.30
Cuzco	.95	.20	.25	.35	.25
San Geronimo	.70	.20	.325	.30	.30
Variegated	.80	.15	.30	.30	.25



CUPULE