Can Palynology be used for Reconstructing the Evolutionary History of Maize Agriculture?

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Abstract: The lack of archaeological or macrobotanical evidence that directly links wild teosinte grass with early domesticated maize requires the exploration of alternative methodologies to document this evolutionary transition. The morphological characteristics and measurements for maize, teosinte and *Tripsacum* pollen are presented to determine if they display sufficient differentiation to be distinguished in fossil pollen records. Analysis of the data reveals a lack of distinguishing morphological characteristics between the pollen grains of these taxa and prevents palynology from be an effective method in documenting the evolutionary history of maize agriculture. Current methods of pollen analysis cannot be employed to document the evolution of teosinte to maize in the Tehuacan Valley of Mexico and pollen is not likely to provide an earlier record of this transition than what is found in the macrobotanical or archaeological evidence.

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Introduction

Palynology, the science of pollen analysis, is a method that has increasingly been applied to solving various problems in prehistoric disciplines. The origins of maize agriculture is one such issue in prehistory that has long fascinated New World palaeoecologists, botanists, and archaeologists, but a thorough reconstruction of this evolutionary process is still largely absent. By the time Europeans had invaded North and South America, maize (*Zea mays*) had become the single most important food resource that was exploited by aboriginal agricultural societies, all the way from the southern extreme in Argentina to its northern limit in southern Canada (Galinat 1985). Over the millennia, maize evolved into hundreds of different races, each developing a specialized adaptation to its environment and cultural influences. As maize was such an important resource and cultural trait for many aboriginal peoples, much research has been devoted to determining its evolution and history of agricultural diffusion (Riley *et al* 1990; Kidder 1992; Fearn and Liu 1995). In order to fully understand the interdependent relationship between human culture and maize agriculture, a thorough understanding of the evolutionary roots of maize must first be developed (Galinat 1985). This paper will explore the possible role that palynology can perform in helping to determine the evolutionary history for domesticated *Zea mays*.

Origins of Maize

It is believed that maize was first domesticated somewhere in Mesoamerica, or possibly further south, from the wild grass teosinte (Beadle 1980:112). Through human selection, the transition from the stalks of wild teosinte grass to the maize cobs probably only took about a century to accomplish; a shorter time span than that required to develop highly productive maize forms (Galinat 1985). One of the main problems in studying the evolutionary history of corn is the lack of archaeological and macrobotanical evidence which directly links teosinte grass to early domesticated maize (Galinat 1985). Beadle (1980:112) concludes that "it now seems quite likely that a teosinte of some 8,000 to 15,000 years ago was the direct ancestor of modern corn and was transformed into a primitive corn through human selection." Based on macrobotanical evidence of fossilized maize cobs and kernels, MacNeish (1970) traced the gradual emergence of domesticated maize in the Tehuacan valley of Mexico. The earliest accepted evidence for domesticated maize was recovered from a Tehuacan rockshelter and was dated by associated charcoal to 5,000 B.C. (Galinat 1985). These finds by MacNeish are the oldest archaeological or macrobotanical evidence of domestic maize recovered from the plant's likely place of origin. According to estimates of the antiquity of maize's origins presented by Beadle (1980:117), there is a gap of about 1,100 years between the available evidence of the initial varieties of primitive domestic corn and its ancestral origin in wild teosinte. As it is believed that it probably only took about a hundred years for the transition from teosinte to maize to occur (Galinat 1985), the intermediate varieties of the two plants will likely be difficult to detect in the archaeological record.

Palynology of Maize Agriculture

Archaeological evidence supports the hypothesis that maize agriculture diffused within the tropics south and east into Central America before it was carried north out of the tropical zone (Fearn and Liu 1995). Microfossil studies of pollen and phytoliths indicate that maize was first introduced into central Panama around 7,000 BP, and at Ecuador around 5,000 BP (Piperno *et al.* 1985:872-874). Maize appears in the tropical Central American microfossil record about 2,000 years before it is found in the archaeological or macrobotanical record. Piperno *et al.* (1985:876) believe that in some areas, pollen and phytoliths may preserve better than maize kernels and cobs, therefore documenting a much earlier arrival of maize into an area than possible with macrobotanical evidence.

The earliest macrofossil evidence for the arrival of maize into the United States dates to 3,000 BP, from the Tornillo Rockshelter in New Mexico (Upham *et al.* 1987). As in tropical Central America, the microfossil evidence for maize in the American Southwest predates the macrobotanical record with *Zea mays* pollen being reported from New Mexico almost 4,000 BP (Simmons 1986:84). The most widely accepted date for maize east of the Mississippi River is dated 1,775 BP from macrofossil evidence at the Icehouse Bottom site in Tennessee. The pollen record also provides convincing evidence for the arrival of maize agriculture in the Eastern United States 1,725 years earlier than reported from macrobotanical evidence, with a date of 3,500 BP on *Zea mays* pollen recovered from Lake Shelby in Alabama (Fearn and Liu 1985). Other discoveries add to the growing amount of literature reporting maize pollen dating earlier than the more widely accepted macrofossil evidence (Delcourt *et al* 1986; Whitehead 1965; Whitehead and Sheehan 1985; Sears 1982 cited in Fearn and Liu 1995). Most pollen dates precede the more frequently cited and widely accepted dates for maize agriculture in North America, just as the microfossil record in tropical Central America extends much further back in time than the macrobotanical record (Fearn and Liu 1995:110).

The Problem

These discrepancies between the pollen and macrobotanical records, in providing dates for the earliest occurrence of maize agriculture outside of Mexico, clearly show that palynology can be a very important method in studying the cultivation history of maize. Considering that the pollen record predates the macrobotanical record for maize in these areas of the United States and Central America, it is possible that a similar discrepancy in ages might exist for the ancestral homeland of maize, the Tehuacan valley in Mexico. It is possible that fossil pollen assemblages may record the initial domestication of maize earlier than the current macrobotanical evidence from the Tehuacan Valley dated to 7,000 BP. Although there is a gap in the archaeological and the macrobotanical records for the transition from teosinte grass to domesticated maize, the pollen record may provide the necessary data to piece together its evolutionary history into primitive forms of corn. In order to test this hypothesis, it is necessary to have a method of identifying fossil pollen of domesticated *Zea mays*. If one can consistently distinguish the pollen of teosinte from that of *Zea mays* accurately, then it may be possible to date the transition from teosinte to maize in high resolution pollen records from the Tehuacan Valley in Mexico. Can *Zea mays* pollen be accurately distinguished from teosinte in order to document this evolutionary transition using fossil pollen records?

Methods of Identifying Fossil Maize Pollen

The large size of maize pollen appears to prevent confusion with any other wild grass pollen except that of the related species *Tripsacum* and teosinte (Irwin and Barghoorn 1962:353). The importance of maize in archaeological studies has necessitated the attempts of palynologists to arrive at an accurate distinction of *Zea mays* pollen from the closely-resembling and often co-occurring pollen of teosinte and *Tripsacum*. This problem is evident in the analysis of grass pollens in general; the singular lack of distinguishing morphological characteristics (Whitehead and Langham 1965:7). There are essentially three interrelated methods that have been used in attempts to distinguish maize pollen from that of other grasses. These criteria are: the size of the pollen grain (Whitehead and Langham 1965:8), the ratio of the dimensions of the annulus and pore related to the size of the grain (Whitehead and Langham 1965:8), and pattern of the grain surface ornamentation as seen by the means of phase contrast and electron microscopy (Rowley 1960:10; Tsukada and Rowley 1964:407). These criteria will be discussed to determine if they offer methods in distinguishing fossil maize and teosinte pollen. Although these studies of maize pollen morphology seem quite old, the parameters outlined in their methods are still employed today for the identification of fossil maize pollen (Simmons 1986; Fearn and Liu 1995).

Identifying Maize Pollen Using Size Measurements

Whitehead and Langham (1965:13-14) conducted experiments on 10 races of teosinte, 12 races of maize, and two races of *Tripsacum dactyloides*, in order to outline parameters to distinguish the pollen of the three species based on quantitative size measurements. One hundred grains were analyzed from each collection and pore size, long axis, and axis/pore ratio were recorded for each grain (Table 1).

	Pollen Grain Size	*Axis/Pore Ratio*	*Pore Size*
Tripsacum measurement range	33.35 – 56.55	3.8 – 7.4	7.25 – 11.60
Tripsacum mean	41.92 ± 8.14	4.94 ± 0.49	
Teosinte measurement range	46.40 – 87.00	3.9 – 9.4	7.25 – 15.95
Teosinte mean	63.56 ± 4.73	5.81 ± 0.63	
Maize measurement range	58.00 – 98.60	4.0 – 8.4	8.70 – 17.40
Maize mean	76.77 ± 4.71	5.68 ± 0.40	

Table 1. *Pollen Size, Axis/Pore Ratio and Pore Size Variations in Tripsacum, Teosinte and Maize. All measurements in microns (μ). (After Whitehead and Langham 1965:13-14).*

Since many factors, such as the environment of preservation and methods of sample preparation, can greatly alter the size of pollen grains and pores, the comparison of fossil and modern maize pollen data sets cannot be directly comparable (Whitehead and Langham 1965:9). Additionally, as grain size will be affected disproportionately more than pore size by different treatments and environments of preservation, then the axis/pore ratios for modern and fossil pollen are not directly comparable either. Hence, fossil and modern maize pollen cannot be directly compared for size even if prepared by the same techniques, nor may fossil grains from different sediment types be directly compared.

Based on these experimental studies, Whitehead and Langham (1965:18-19) conclude that quantitative size measurements present many problems in distinguishing the pollen of maize and teosinte. Since the distribution of the axis/ pore ratio measurements for teosinte completely overlap with that for maize, it appears that this ratio measurement has little or no diagnostic value for distinguishing maize and teosinte pollen. The data collected suggest that overall grain size and pore size are more reliable criteria for distinguishing maize and teosinte pollen. Although this certainly does not permit the identification of individual grains from the zone of overlap, distinguishing the species of grains based on these criteria is possible if one uses a large enough data set. Any non-*Tripsacum* individual grains less than 58µ in size could be identified as teosinte, and any grains larger than 88µ as maize. More generally, it is likely that grains larger than 73µ (2 standard deviations above the teosinte mean) can be identified as maize, and any less than 66µ (2 standard deviations below the maize mean), teosinte (Whitehead and Langhan 1965:18). A large data set is required when using such mean size values to distinguish the pollen of maize and teosinte. Although it may be very difficult to consistently distinguish individual pollen grains of teosinte and maize, when applied to these size parameters, it is likely that a significant statistical variation between the two species will become evident in a large data set.

In a similar study using modern maize pollen measurement data, Kurtz and colleagues (1960) sought to determine the environmental effects on the size of maize pollen and its application to identifying fossil maize. It was determined that both the axis length and the diameter of the pore varied considerably among the several different environmental conditions to which they were exposed. The axis length was found to vary much more than pore size under various environmental conditions. Therefore, it was suggested that the axis/pore ratio value would be a better means of identification of maize pollen (Kurtz *et al.* 1960:93-94). As with Whitehead and Langhan (1965), Kurtz and colleagues (1960) found a large zone of overlap between the axis/pore ratio between teosinte, *Tripsacum* and maize. Their study indicates that the axis/pore ratio fails to describe the characteristics of maize pollen with a high degree of reliability. Since such variations in pollen measurements from different environmental conditions exist, the use of modern maize pollen data to distinguish fossil maize pollen from that of teosinte or *Tripsacum* is problematic.

Surface Morphology of Maize Pollen

Electron microscopy was used by Tsukada and Rowley (1964) to determine if surface morphology could be used to identify fossil maize pollen. The surface structure of fossil grains were determined to closely resemble that of contemporary modern maize pollen as both modern and fossil pollen were found to contain spinules measuring approximately 0.3µ in height and tiny holes 40 - 80 mµ in diameter. When the surface was cleaned and a deep impression left for the negative replica, both the total number and density of surface spinules on the fossil maize pollen were found to be very similar to that found on the modern maize pollen. It was also noted that the density of spinules per unit area varied considerably in the modern maize pollen depending on its source, viability, and preparation treatment. On the other hand, the total number of spinules per grain was independent of the grain size and seems to be fairly consistent for material from the same source. Tsukada and Rowley (1964:410) believe that "the correlation of the spinulatus density to size and the total spinule number may provide a method for estimating the rate of change in maize pollen with time as well as offering one more test for the specific identification of maize pollen." Research by Tsukada and Rowley (1964:410) suggests that the correlation of spinulatus density with the total amount of spinules on pollen grains may be the best microscopy analysis to assist with identification of maize pollen.

Light microscopy research conducted by Rowley (1960) suggests the possibility of distinguishing *Tripsacum*, teosinte, and maize pollen on the basis of surface sculpturing characteristics. The surface sculpturing of *Tripsacum* pollen is verrucate, and in many cases columellae can be seen coinciding with the verrucae. Rowley (1960) determined that the location of the verucae spinules on the tectum surface of *Trispsacum* coincides exactly with the position of the columellae beneath the tectum. In contrast to the surface of *Tripsacum*, the surface sculpturing of both maize and teosinte appear to be psilate under phase and full-cone illumination (Whitehead and Langham 1965:17). The pronounced columellae for maize and teosinte pollen are relatively large, randomly distributed, and show no tendency for clumping. Since the collumelae for maize and teosinte pollen are randomly distributed and do not appear to have clumping, this criteria can be used to distinguish them from the pollen of *Tripsacum* which has columellae that coincide with location of the spinules on the surface. Although these surface structural criteria are can be used to distinguish maize and teosinte pollen from that of *Tripsacum*, it does little for solving the problem of separating maize from teosinte grains.

Discussion

This paper has explored the possibility of distinguishing fossil maize pollen from wild teosinte in order to document this evolutionary transition in fossil pollen records. By reviewing the available literature, involving studies that distinguish fossil maize pollen from that of teosinte and *Tripsacum*, this paper presents the various methods that researchers have employed in attempting to solve this problem. Based on the methods of analyzing grain size, axis/pore ratio, and surface sculpturing morphology, it appears that it is nearly impossible to consistently distinguish the pollen of teosinte from that of domestic *Zea mays*. Since there is a the lack of unique identifying features for each species, distinguishing the species of an individual grain is almost impossible when analyzing samples that contain both teosinte and maize pollen. There is too great an overlap when using grain size and axis/pore ratio for individual identification. The surface structures of teosinte and maize pollen are nearly identical. Therefore electron or light microscopy analysis is essentially useless for distinguishing these species. The overall variation in pollen characteristics of fossil teosinte and maize is so slight that accurate identification cannot be consistently reliable. It appears that only the variational extremes of maize and teosinte can be identified with assurance. Some general trends for the differences in grain size and pore size do exist for teosinte and maize, and it may be possible to distinguish the two species within a large data set of, at minimum, five hundred grains from each sample. Given that relatively few fossil pollen grains resembling maize are usually found in sediment samples (Kurtz *et al.* 1960:92), it is highly unlikely that a large data set, one that may statistically distinguish teosinte from maize, will be encountered.

Conclusions

Palynology in not an effective method for studying the evolutionary history from wild teosinte grass to primitive varieties of domestic maize. As there are no reliable methods for distinguishing the fossil pollen grains of teosinte from maize, routine pollen counting analysis would not be able to accurately trace the transition from teosinte to maize in pollen records of the Tehuacan valley in Mexico. The evolutionary transition would have occurred within a short time period, possibly only one-century, and detecting this early appearance of maize in pollen records would be virtually impossible. Pollen evidence of maize agriculture has proven to be reliable in areas outside Mexico, far from the natural biogeographic boundaries of wild teosinte. Since teosinte did not exist in the United States or in Central America, maize pollen would be easily identifiable in the pollen record, and provide records for the initial occurrences of maize agriculture. The pollen records for Mexico may contain maize pollen earlier than the earliest dated macrobotanical evidence, but this is impossible to detect using the current methods of pollen analysis.

The environmental effects on pollen, along with the different morphological characteristics of the different races of fossil maize and teosinte, make distinguishing the pollen of these species even more problematic. The earliest forms of maize were likely very similar to the wild teosinte plants; thus, detecting the initial stages of maize evolution in the archaeological record is also uncertain. The evolution associated with the initial transition to domestic forms of maize was probably too rapid for the morphology of pollen to develop individual characteristics that could be used to accurately distinguishing teosinte and maize pollen.

In conclusion, palynology cannot be employed to document the evolutionary history of teosinte to maize through pollen records from the Tehuacan valley in Mexico, and pollen is not likely to provide an earlier record of this transition than what is found in the macrobotanical or archaeological evidence. As the archaeological, macrobotanical, and palynological records have all failed to identify a direct evolutionary link from wild teosinte to early forms of domesticated maize, the problem of clearly dating and reconstructing the cultural transition to maize agriculture in Mesoamerica remains left to scientific inquiry and future investigation.

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References Cited

Beadle, G.W.
1980 The Ancestry of Corn.
Scientific American 242(1):112-119.

Delcourt, P.A., H.R. Delcourt, P.A. Cridlebaugh, and J. Chapman
1986 Holocene Ethnobotanical and Paleoecological Record of Human Impact on Vegetation in the Little Tennessee River Valley, Tennessee.
Quaternary Research 25:330-349.

Fearn, M.L., and K.-B. Liu
1995 Maize Pollen of 3500 B.P. from Southern Alabama.
American Antiquity 60:109-117.

Galinat, W.C.
1985 Domestication and Diffusion of Maize.
In ***Prehistoric Food Production in North America.***
Richard I. Ford, ed. Pp. 245-278.
Ann Arbor: Museum of Anthropology, University of Michigan.

Irwin, H.T., and E.S. Barghoorn
1962 Criteria in Distinguishing the Pollen of Maize, Teosinte, and *Tripsacum.*
Pollen et Spores 4:352-353.

Kidder, T.R
1992 Timing and Consequences of the Introduction of Maize Agriculture in the Lower Mississippi Valley.
North American Archaeologist 13(1):15-41.

Kurtz, E.B. Jr., J.L. Liverman, and H. Tucker
1960 Some Problems Concerning Fossil and Modern Corn Pollen.
Bulletin of the Torrey Botanical Club 87(2):85-94.

MacNeish, R.S., editor
1970 ***The Prehistory of the Tehuacan Valley.***
Austin: University of Texas Press.

Piperno, D.R., K.H. Clary, R.G. Cooke, A.J. Ranere, and D. Weiland
1985 Preceramic Maize in Central Panama: Phytolith and Pollen Evidence.
American Anthropologist *87*:871-878.

Riley, T.J., R. Edging, and J. Rossen
1990 Cultigens in Prehistoric Eastern North America.
Current Anthropology 31:525-541.

Rowley, J.R.
1960 The Exine Structure of "Cereal" and "Wild" Type Grass Pollen.
Grana Palynologica *2*:9-15.

Simmons, A.H.
1986 New Evidence for the Early Use of Cultigens in the American Southwest.
American Antiquity 51:73-89.

Tsukada, M., and J.R. Rowley
1964 Identification of Modern and Fossil Maize Pollen.
Grana Palynologica 5(3):406-412.

Upham, S., R.S. MacNeish, W.C. Galinat, and C.M. Stevenson
1987 Evidence Concerning the Origin of Maiz de Ocho.
American Anthropologist 89:410-419.

Whitehead, D.R.
1965 Prehistoric Maize in Southeastern Virginia.
Science 150:881-882.

Whitehead, D.R., and E.J. Langham
1965 Measurement as a Means of Identifying Fossil Maize Pollen.
Bulletin of the Torrey Botanical Club 92(1):7-20.

Whitehead, D.R., and M.C. Sheehan
1985 Holocene Vegetation Changes in the Tombigbee River Valley, Eastern Mississippi.
American Midland Naturalist 113(1):122-137.