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Letters

Phytolith Morphology

As investigators who have worked closely with phytolith analysis since its inception and development as a modern research tool in paleoethnobotany, we challenge statements made in a letter by Irwin Rovner (*Science's* Compass, 22 Jan., p. 488) that questions the identification of phytoliths in archaeological sediments.

First, Rovner's contention that phytoliths the same as those produced in squash (*Cucurbita*) rinds also occur in two other tropical families is incorrect. This contention is based on photographs published by others, including one of us (1, 2). However (1), which concerned the African flora, did not compare the taxa in question, and (2), following (3) and using a large sample of plants, noted that spherical phytoliths with deeply scalloped surfaces of continuous cavities that originate from *Cucurbita* fruit rinds could also be distinguished in the Neotropics. Reproductive structures from many taxa contribute distinctive phytoliths not found in vegetative parts (4-9). Annonaceae and Burseraceae phytoliths, considered by Rovner to be the same as those from squash fruits, are formed in leaves, have surface ornamentations unlike those found on squash phytoliths, and are uncharacteristic of phytoliths from fruits and seeds (1-10).

The identification of archaeological *Cucurbita* phytoliths on morphological grounds (11) is further supported by recent studies showing that they do not occur in the approximately 3500 species of plants from 150 families represented in our modern reference collections from the Neotropics [including 45 species from 22 different genera in the Cucurbitaceae (12)] and from tropical Asia (6-9, 13) or in the many species from other regions of the world studied recently (1, 5, 14, 15).



Excavations at China's Diaotonghuan Cave revealed a sequence of rice phytoliths, from which archaeologists are tracing the transition from wild to domestic rice.

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Second, there is no basis for Rovner's blanket statement that moisture variation causes substantial variation in phytolith size and, therefore, that increase in size of archaeological *Cucurbita* phytoliths could be explained by climatic change. Correlations between size and moisture have been studied only for leaf phytoliths in a few species of grasses, and these studies did not address the more important question of whether intraspecific variation conflated interspecific comparison. Our examination of phytolith size in six different populations of two wild *Cucurbita* species sampled from localities in Central America, where growing season precipitation differs considerably, indicated that intraspecific variability is unremarkable (11). Rather, phytolith size in these and other modern wild, semidomesticated and domesticated squashes, like seed size, was strongly correlated with the size of the fruit ($P < 0.001$; $R^2 = 0.894$) (11). No wild squash in five different species we studied contributed phytoliths with length and breadth dimensions as large as those found in South American

domesticated squashes (11).

Our archaeological samples from the Vegas site in southwest Ecuador demonstrated a dramatic increase of size in phytoliths from squash rinds between 10,000 years B.P. (before the present) and 7000 years B.P. The sizes of the earliest phytoliths fell within the range of modern, wild squash, and the sizes of the later phytoliths overlapped the range of modern domesticated species (11). Other phytolith evidence from Vegas pointed to little or no moisture increase during this period, and paleoecological records from the region indicate that the period was probably the most stable climatic interval of the Holocene (11, 16). Further, a recent analysis of a Vegas phytolith sample from before 10,000 years B.P. (12) indicated that no change in squash phytolith size occurred between about 10,500 years B.P. and 9700 years B.P., when regional precipitation probably did increase as a result of the environmental changes that accompanied the close of the Pleistocene (11). Therefore, as with archaeological seed analysis (17), our data likely indicate that early squash domestication occurred.

Third, Rovner's assertion that phytoliths are difficult to identify at refined taxonomic levels is contradicted by a large body of empirical evidence accumulated in the past 15 years by investigators around the world who, for the first time, closely studied phytoliths in a wide sample of angiosperms (1-10, 13-15, 18). As with *Cucurbita*, three different sets of researchers agree that *Oryza* (rice) can be identified on the basis of the morphology of a single type of phytolith that occurs in reproductive organs (in this case, the glume) (7, 19-21). Our classifications have been validated by multivariate analysis, namely, multiple discriminant functions. In our studies of rice, the measurements were specifically taken to capture size and shape because, as is well known in taxonomy, these attributes together are often necessary for efficient classification (20). Since wild and domesticated *Oryza* can be distinguished in a randomly reserved test set from functions prepared from the training set (7), Rovner's objections that such classification is not yet possible are refuted by the empirical evidence. Our work with maize used frequencies of phytolith variants where the variants are defined by shape as well as by a size measurement; once again, our success in prediction is due to including both size and shape in the analysis (18).

Finally, Rovner's statement that early maize phytoliths from Ecuador are "larger than the size values presented for any and every modern reference maize tested" is contrary to the evidence. Rovner could be referring to one Valdivia sample that had a slightly increased fraction (by about 10%) of "extra-large size" phytoliths (those measuring from 20 to 25 micrometers in width) (22). However, when the broad size categories are converted into average mean widths, these phytoliths are smaller than many modern maize races (18).

Studies of agricultural origins demand the highest standards of research, and interested scholars from other disciplines deserve reliable information on this crucial transition in human prehistory.

Dolores R. Piperno,

Center for Tropical Paleocology and Archaeology,
Smithsonian Tropical Research Institute,
Balboa, Panama;

Deborah M. Pearsall,

Robert A. Benfer Jr.,

Department of Anthropology,
American Archaeology Division,
University of Missouri,
Columbia, MO 65211-0001, USA;

Lisa Kealhofer,

Department of Anthropology,
College of William and Mary,
Williamsburg, VA 23187-8795, USA;

Zhijun Zhao,

Institute of Archaeology,
Chinese Academy of Social Sciences,
Beijing, People's Republic of China;

Qinhua Jiang,

Department of Geology,
Peking University, Beijing

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