The Initial Domestication of Cucurbita pepo in the Americas 10,000 Years Ago

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Squash seeds, peduncles, and fruit rind fragments from Archaic period stratigraphic zones of Guila\' Naquitz cave in Oaxaca, Mexico, are assigned to Cucurbita pepo on the basis of diagnostic morphological characters and identified as representing a domesticated plant on the basis of increased seed length and peduncle diameter, as well as changes in fruit shape and color, in comparison to wild Cucurbita gourds. Nine accelerator mass spectrometer radiocarbon dates on these specimens document the cultivation of C. pepo by the inhabitants of Guila\' Naquitz cave between 10,000 to 8000 calendar years ago (9000 to 7000 carbon-14 years before the present), which predates maize, beans, and other directly dated domesticates in the Americas by more than 4000 years.

The initial domestication of plants and animals and the transition from hunting and gathering to an agricultural way of life occurred independently in at least seven different primary centers of agricultural origin worldwide (1). In Mesoamerica, three major crop plants were first domesticated: maize (Zea mays), the common bean (Phascolus vulgaris), and squash (Cucurbita pepo). Although there has been considerable recent biological research on the identity and present-day geographical range of the wild progenitors of these three major crop plants (1, 2), all of the archaeological information regarding their initial domestication in Mexico comes from a series of five caves excavated in the 1950s and 1960s:

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Romero's and Valenzuela's caves near Ocampo, Tamaulipas (3); Coxcatlán and San Marcos caves in Tehuacán, Puebla (4); and Guila\' Naquitz cave in Oaxaca (5). On the basis of temporally diagnostic artifacts associated with early domesticated plants in these caves, along with conventional radiocarbon age determinations on associated materials, the domestication of these three major crop plants was thought to have taken place 7000 to 10,000 calendar years before present (B.P.) (3–5). Recent reanalysis of the earliest domesticated maize, common bean, squash, and bottle gourd (Lagenaria siceraria) specimens from four of these five caves, however, and their direct dating by the small sample accelerator mass spectrometer (AMS) radiocarbon method, have produced much more recent ages (3, 6–8).

These much younger AMS age determinations for the earliest crop plants from Coxcatlán, Romero's, San Marcos, and Valenzuela's caves have in turn led to suggestions that the transition from hunting and gathering to incipient agricultural economies in Mesoamerica occurred much more recently than 7000 to 10,000 calendar years ago (6). Here I report results of the reanalysis and direct AMS dating of the earliest domesticate from Guila\' Naquitz, the fifth of these Mesoamerican caves.

Guila\' Naquitz cave has an uppermost late Classic period layer 20 cm thick (zone A, 620 to 740 A.D.) that is rich in storage pits and a variety of domesticated plants. Beneath zone A, four more layers (zones B to D) each predates maize, beans, and other directly dated domesticates in the Americas by more than 4000 years.
blage from zones B through D of Guila´ Naquitz was found to include 276 fruit rind fragments, nine measurable seeds, and 14 measurable peduncles and fruit end fragments having peduncle scars (10) (Fig. 1). Exhibiting a diagnostic cross-section cellular morphology (3), the 276 Cucurbita rind fragments were all within the thickness range for present-day wild Cucurbita gourds (11–13) and thus provided no unequivocal evidence for the presence of domesticated C. pepo. There was, however, a substantial increase in rind thickness in zone B (Fig. 1), implying a change in fruit morphology and possibly the presence of a domesticated type of Cucurbita in the zone B habitats of the cave. Paralleling this increase in rind thickness, the size of peduncles increases substantially in zone B (Fig. 1), signaling the presence of a clearly domesticated form of C. pepo squash. The peduncles of all documented taxa of wild Cucurbita gourds consistently fall below 10 mm in maximum basal diameter (11–14). Seven of the nine zone B peduncles and fruit end peduncle scars exceed this 10-mm boundary (range 11.4 to 23.6 mm). The largest of the zone B peduncles (Fig. 2A) and the two largest fruit end fragments having peduncle scars, all of which exhibit the alternating major-minor 10-ridge morphology that is diagnostic for C. pepo (3), yielded AMS 14C dates of 6980 to 7340 14C years B.P. (ca. 7700 to 8200 calendar years B.P.) (Table 1 and Fig. 1) (15). The two large fruit end fragments provide further evidence of domestication in that they angle abruptly down and away from the peduncle scar in a zucchini-like fashion, a fruit form distinctly different from the globular-to-ovoid shape characteristic of wild Cucurbita gourds (11–14). Finally, in contrast to the typical green-and-white-striped to white rind color of modern wild Cucurbita gourds, one of the fruit ends from zone B is bright orange (Fig. 2B), a color comparable to that of modern varieties of the Mexican domesticated lineage C. pepo ssp. pepo (16).

These changes in shape and color, which appear to indicate that humans were deliberately selecting for certain fruit characteristics in C. pepo by ca. 7000 14C years B.P. (ca. 8000 calendar years B.P.), are preceded by

![Fig. 1. Size measurements and AMS 14C dates for Guila´ Naquitz Cucurbita fruit rind, seeds, and peduncles (A, zone D; B, zone C; C, zone B). Rind thickness values, given as mean, SD, and range, are as follows: A, 0.94, 0.22, 0.5 to 1.6; B, 0.81, 0.22, 0.3 to 1.7; C, 1.15, 0.31, 0.5 to 2.0.](Image 64 to 212x735)

![Fig. 2. (A) Cucurbita pepo peduncle from zone B of Guila´ Naquitz that yielded an AMS 14C date of 7340 ± 60 14C years B.P. (note diagnostic alternating large and small ridges). (B) Cucurbita pepo fruit end fragment from zone B of Guila´ Naquitz that retains orange rind color and yielded an AMS 14C date of 6980 ± 50 14C years B.P. (C) A squash seed from zone C of Guila´ Naquitz 13.9 mm in length that exhibits marginal ridge and hair morphology diagnostic of C. pepo and yielded an AMS 14C date of 8910 ± 50 14C years B.P.](Image 64 to 212x735)

Table 1. Nine AMS 14C dates on Cucurbita seed and peduncle specimens from Guila´ Naquitz cave.

<table>
<thead>
<tr>
<th>Provenience (zone–square–INAH catalog number)</th>
<th>Material and size (mm)*</th>
<th>Beta analytic lab number</th>
<th>Age in radiocarbon years B.P.†</th>
<th>Calibration curve intercept (years B.P.)‡</th>
<th>Dendrocalibrated 2σ age range (years B.P.)§</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-B9-58 Peduncle scar, 23.6</td>
<td>β07240</td>
<td>6980 ± 50</td>
<td>7755</td>
<td>7900 to 7655</td>
<td></td>
</tr>
<tr>
<td>B-C11-42 Peduncle scar, 20.2</td>
<td>β07238</td>
<td>7280 ± 60</td>
<td>8065</td>
<td>8145 to 7930</td>
<td></td>
</tr>
<tr>
<td>B-B9-58 Peduncle, 19.0</td>
<td>β07239</td>
<td>7340 ± 60</td>
<td>8115</td>
<td>8185 to 7965</td>
<td></td>
</tr>
<tr>
<td>B-C11-7 Seed, 12.0 × 7.0</td>
<td>β01406</td>
<td>7610 ± 60</td>
<td>8375</td>
<td>8435 to 8305</td>
<td></td>
</tr>
<tr>
<td>B-C11-7 Seed, 12.1 × 7.3</td>
<td>β01405</td>
<td>7690 ± 50</td>
<td>8415</td>
<td>8520 to 8365</td>
<td></td>
</tr>
<tr>
<td>B-C11-5 Seed, 12.5 × 7.9</td>
<td>β100763</td>
<td>7710 ± 50</td>
<td>8425</td>
<td>8545 to 8370</td>
<td></td>
</tr>
<tr>
<td>B-C11-7 Seed, 11.4 × 7.2</td>
<td>β01404</td>
<td>7720 ± 60</td>
<td>8430</td>
<td>8560 to 8370</td>
<td></td>
</tr>
<tr>
<td>C-E9-14 Seed, 13.8 × 7.4</td>
<td>β100764</td>
<td>8910 ± 50</td>
<td>9925</td>
<td>9985 to 9870</td>
<td></td>
</tr>
<tr>
<td>B-E11-23 Seed, 13.2 × 8.8</td>
<td>β100766</td>
<td>8990 ± 60</td>
<td>9975</td>
<td>10,035 to 9905</td>
<td></td>
</tr>
</tbody>
</table>

*Measurements for seeds, maximum length and width; for peduncles, maximum basal diameter; for peduncle scars, maximum diameter. †Uncalibrated conventional 14C age of specimens, in 14C years B.P. (±1σ). ‡Intercept between the conventional 14C age and the dendrocalibrated calendar time scale, in calendar years B.P. (Pretoria calibration procedure program, Beta Analytic). §Two-sigma dendrocalibrated age range for specimens, in calendar years B.P.
other morphological changes that reflect an earlier automatic response on the part of the plants to the selective pressures of seedbed and harvesting (the adaptive syndrome of domestication) (1, 2, 17). The intact Cucurbita seeds from the Archaic period occupations of the cave provide evidence, in terms of size increase, that such an adaptive response to seedbed selective pressures had occurred by ca. 9000 14C years B.P. (ca. 10,000 calendar years B.P.). In the initial analysis of the Cucurbita assemblage from the cave (9), no clear morphological criteria were stated for assigning domesticated status to the Guila Naquitz Cucurbita seeds, including the single seed recovered from zone D that was identified as domesticated. An increase in size above that documented for wild seeds has been the standard criterion for identifying the seeds of domesticated C. pepo (11–13, 17). The 35 late Pleistocene (ca. 12,500 14C years B.P.) seeds of a wild Cucurbita gourd recently recovered from American mastodon (Mammuthus americanum) dung deposits at the Page-Ladson site in Florida (12) provide a good wild baseline of comparison. The single seed from zone D of Guila Naquitz has length and width dimensions (10 by 7 mm) that fall close to the average values (9.87 by 6.62 mm) of the Page-Ladson wild seed assemblage (range 8.73 to 11.15 mm and 5.07 to 7.60 mm), and thus it cannot be considered as evidence for the presence of domesticated C. pepo. Of the five measured seeds from zone C of Guila Naquitz, four fall within or close to the upper end of the Page-Ladson size range in terms of length, although one has a length of 13.8 mm (Table 1 and Fig. 1). The AMS 14C data on this largest of the zone C seeds is 8910 14C years B.P. (ca. 9900 calendar years B.P.) (Table 1 and Fig. 1). Seven of the eight zone B seeds also exceed the size range of the wild comparative baseline population (range 11.4 to 17.0 mm) (Fig. 1). Samples from five of these seven large zone B seeds have AMS 14C ages of 7610 to 8990 14C years B.P. (ca. 8400 to 10,000 calendar years B.P.) (Table 1 and Fig. 1). The largest and oldest of these dated zone B seeds was comparable in both size and age to the AMS-dated zone C seed. Taken together, these two seeds, both of which exhibit marginal ridge and hair characteristics diagnostic for C. pepo (3) (Fig. 2C) and are 18 to 24% larger than the largest of the wild baseline Page-Ladson seeds, imply the presence of domesticated C. pepo in Guila Naquitz cave by ca. 9000 14C years B.P. (ca. 10,000 calendar years B.P.).

The temporal and developmental pattern of automatic adaptive response (increase in seed size) preceding deliberate human selection (change in fruit shape and color) in the Guila Naquitz squash closely parallels the developmental sequence documented for the domestication of the other major lineage of C. pepo squashes (C. pepo ssp. oitera) in eastern North America, in which an increase in seed size preceded any changes in fruit morphology (11, 16). The domesticated C. pepo from Guila Naquitz opens up considerable room for debate regarding the timing, context, and causes of agricultural origins in Mesoamerica, while also underscoring the need for further excavation of early agricultural cave and river valley settlements of the Archaic period in different regions of Mexico.

REFERENCES AND NOTES

10. The Guila Naquitz cucurbit assemblage is now curated at the Laboratorio de Paleobotánica, Instituto Nacional de Antropología e Historia (INAH), Mexico, Distrito Federal. The seed, and peduncle specimens illustrated in the original analysis (9) are not present in the INAH collections. As a result, the seed and peduncle specimens illustrated in (9) are not included in this analysis. Seed measurements provided in (9), however, are included in Fig. 1.
15. The as yet undated large peduncle from zone C (Fig. 1) may indicate an even earlier increase in fruit size, given that it is from the same provenance (E9) as the domesticated C. pepo seed that yielded an AMS radiocarbon date of 8910 14C years B.P. (Table 1 and Figs. 1 and 2C).
18. Figure 1 is by M. Bakry and Fig. 2 photographs are by C. Hansen. I thank INAH for permission to sample Guila Naquitz specimens for AMS 14C dates; F. Sánchez, director of the Laboratorio de Paleobotánica, INAH, and J. L. Alvarado for their kind hospitality and their consultation on the analysis; J. L. Alvarado, D. Decker-Walters, K. Flannery, G. Fritz, L. Kaplan, L. Newsom, F. Sanchez, P. J. Watson, and M. Zeeder for comments on the manuscript; and Y. Sugura and C. Castillo, without whose assistance this research would not have been possible.

28 January 1997; accepted 4 March 1997

North and Northeast Greenland Ice Discharge from Satellite Radar Interferometry
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Ice discharge from north and northeast Greenland calculated from satellite radar interferometry data of 14 outlet glaciers is 5.5 times that estimated from iceberg production. The satellite estimates, obtained at the grounding line of the outlet glaciers, differ from those obtained at the glacier front, because basal melting is extensive at the underside of the floating glacier sections. The results suggest that the north and northeast parts of the Greenland ice sheet may be thinning and contributing positively to sea-level rise.