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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 Guilá 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 Guilá 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 (*Phaseolus 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: Romero's and Valenzuela's caves near Ocampo, Tamaulipas (*3*); Coxcatlán and San Marcos caves in Tehuacán, Puebla (*4*); and Guilá 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 (*8*). Here I report results of the reanalysis and direct AMS dating of the earliest domesticate from Guilá Naquitz, the fifth of these Mesoamerican caves.

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Guilá 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 through E) contain evidence of a series of short-term seasonal occupations by small family groups. These zones were dated by conventional radiocarbon age determinations to circa (ca.) 8500 to 10,500 calendar years B.P. and were thought to span the transition from hunting and gathering to incipient agriculture in the region (*5*). In the initial analysis of *Cucurbita* material from these Archaic period zones of Guilá Naquitz, the earliest apparent evidence for this agricultural transition consisted of a single seed recovered from zone D that was identified as being from domesticated *C. pepo* and believed to be 9800 years old on the basis of a conventional radiocarbon date on associated wood charcoal (*9*). Seeds and peduncles of domesticated *C. pepo* were also reported from zones B and C of the cave, along with thin rind fragments, small seeds, and small peduncles of a wild *Cucurbita* gourd.

When restudied, the *Cucurbita* assem-

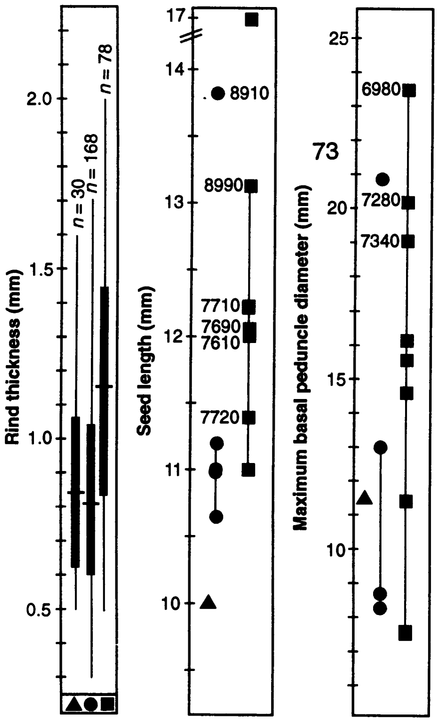

Fig. 1. Size measurements and AMS ^{14}C dates for Guilá Naquitz *Cucurbita* fruit rind, seeds, and peduncles (▲, zone D; ●, zone C; ■, zone B). Rind thickness values, given as mean, SD, and range, are as follows: ▲, 0.84, 0.22, 0.5 to 1.6; ●, 0.81, 0.22, 0.3 to 1.7; ■, 1.15, 0.31, 0.5 to 2.0.

Table 1. Nine AMS ^{14}C dates on *Cucurbita* seed and peduncle specimens from Guilá Naquitz cave.

Provenience (zone–square–INAH catalog number)	Material and size (mm)*	Beta analytic lab number	Age in radiocarbon years B.P.†	Calibration curve intercept (years B.P.)‡	Dendrocalibrated 2σ age range (years B.P.)§
B-B9-58	Peduncle scar, 23.6	β97240	6980 ± 50	7755	7900 to 7655
B-C11-42	Peduncle scar, 20.2	β97238	7280 ± 60	8065	8145 to 7930
B-B9-58	Peduncle, 19.0	β97239	7340 ± 60	8115	8185 to 7965
B-C11-7	Seed, 12.0 × 7.0	β91406	7610 ± 60	8375	8435 to 8305
B-C11-7	Seed, 12.1 × 7.3	β91405	7690 ± 50	8415	8520 to 8365
B-C11-5	Seed, 12.5 × 7.9	β100763	7710 ± 50	8425	8545 to 8370
B-C11-7	Seed, 11.4 × 7.2	β91404	7720 ± 60	8430	8560 to 8370
C-E9-14	Seed, 13.8 × 7.4	β100764	8910 ± 50	9925	9985 to 9870
B-E11-23	Seed, 13.2 × 8.8	β100766	8990 ± 60	9975	10,035 to 9905

*Measurements for seeds, maximum length and width; for peduncles, maximum basal diameter; for peduncle scars, maximum diameter. †Uncalibrated conventional ^{14}C age of specimens, in ^{14}C years B.P. ($\pm 1\sigma$). ‡Intercept between the conventional ^{14}C 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.

blage from zones B through D of Guilá 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 habitations 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 ^{14}C dates of 6980 to 7340 ^{14}C 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 ^{14}C years B.P. (ca. 8000 calendar years B.P.), are preceded by

Fig. 2. (**A**) *Cucurbita pepo* peduncle from zone B of Guilá Naquitz that yielded an AMS ^{14}C date of 7340 ± 60 ^{14}C years B.P. (note diagnostic alternating large and small ridges). (**B**) *Cucurbita pepo* fruit end fragment from zone B of Guilá Naquitz that retains orange rind color and yielded an AMS ^{14}C date of 6980 ± 50 ^{14}C years B.P. (**C**) A squash seed from zone C of Guilá Naquitz 13.8 mm in length that exhibits marginal ridge and hair morphology diagnostic of *C. pepo* and yielded an AMS ^{14}C date of 8910 ± 50 ^{14}C 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 ^{14}C 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 Guilá 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 ^{14}C years B.P.) seeds of a wild *Cucurbita* gourd recently recovered from American mastodon (*Mammut 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 Guilá 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 Guilá 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 Figs. 1 and 2C). The AMS ^{14}C date on this largest of the zone C seeds is 8910 ^{14}C 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 ^{14}C ages of 7610 to 8990 ^{14}C 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* ssp. *pepo* in Guilá Naquitz cave by ca. 9000 ^{14}C 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 Guilá Naquitz squash closely parallels the developmental sequence documented for the domestication of the other major lineage of *C. pepo* squash (*C. pepo* ssp. *ovifera*) in eastern North America, in which an increase in seed size preceded any changes in fruit morphology (*11, 16*). The domesticated *C. pepo* from Guilá 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.

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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 3.5 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.

The traditional view on the mass balance of the Greenland ice sheet is that accumulation of mass (mostly snow) in the interior regions is released to the ocean through surface ablation (or melting) and calving of icebergs (*1*). Of all three components of the mass balance, snow accumulation is the best known from measurements of snow pits and ice cores across the ice sheet (*2*). Observations of surface melt rates are comparatively limited and restricted to the western marginal zone (*3*). Iceberg calving is the least known of the components (*4*). Iceberg production has been estimated in the west (*5*), north, and northeast (*6*) of Greenland by means of repeated aerial photography. The velocity of the calving front is measured by tracking distinctive patterns of crevasses over time. Ice thickness is deduced from the height of the calving front. Immediately inland of the calving front, ice thickness is not well known (*7*), surface features are more subdued, and locating the grounding line, which is where a glacier detaches

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