Reports

Chenopodium as a Prehistoric Domesticate in Eastern North America: Evidence from Russell Cave, Alabama

Abstract. *Approximately 50,000 carbonized fruits of the species* Chenopodium berlandieri *recovered from Russell Cave, Alabama, and dating to 1975 ± 55 before the present, exhibit a set of interrelated morphological characteristics reflecting domestication (thin testa, truncate margin, rectanguloid fruit cross section, ligulate cotyledons, and increased internal fruit volume). These morphological characteristics establish the presence of a domestic variety of* Chenopodium *in the eastern United States by 2000 years ago.*

Before the introduction of maize (*Zea mays*) about A.D. 400 (*1*), garden plots of the eastern woodlands of the United States contained only four species of plants with the morphological characteristics associated with domestication: bottle gourd (*Lagenaria siceraria*) (*2*); squash (*Cucurbita pepo*) (*2, 3*); and two indigenous annual plant species that produced oily seeds, marsh elder (*Iva annua*) (*1, 4*) and sunflower (*Helianthus annuus*) (*1, 4*). Tobacco (*Nicotiana* sp.) was also present in the eastern United States by 2000 years ago (*5, 6*). In addition, four indigenous species of starchy seed annuals that have not been shown to exhibit morphological changes associated with domestication were, nonetheless, economically important in second millennium garden plots: maygrass (*Phalaris caroliniana*), knotweed (*Polygonum erectum*), little barley (*Hordeum pusillum*), and goosefoot (*Chenopodium*) (*5, 6*).

The possibility that *Chenopodium* may have been a prehistoric domesticate in the eastern United States was first proposed over 50 years ago but subsequently rejected (*7*). However, analysis of Ozark rock shelter archeobotanical collections indicates a likely late prehistoric (after A.D. 1000) introduction into the eastern woodlands of a Mexican domesticated variety of chenopod (*Chenopodium berliandieri* ssp. *nuttalliae* cv. "huazontle"), which lacked the distinctive hard outer seed coat or testa of the wild chenopods (*8, 9*). In addition, both Middle Woodland (1900 to 1700 years ago) and Late Woodland (1500 to 1200 years ago) sites in Illinois have yielded chenopod fruits with a truncate margin and apparent thin outer seed coat, indicating that another domestic variety of chenopod may have been present in the east at an earlier date (*4, 5, 9*). Similar thin testa chenopod fruits have been recognized in Terminal Archaic (2700 to 2000 years ago) archeobotanical collections from Salts Cave, Kentucky, suggesting the possible presence of a domestic chenopod by this early time period (*1*).

Evidence that *Chenopodium* was present as a domesticate within the second and third millennium garden plots of the eastern United States comes from analysis of a collection of approximately 50,000 carbonized *Chenopodium* fruits (seeds with a thin adherent pericarp) from Russell Cave, Alabama. The Russell Cave fruits exhibit several of the distinctive characteristics associated with the adaptive syndrome of domestication in *Chenopodium* (*8, 10–13*).

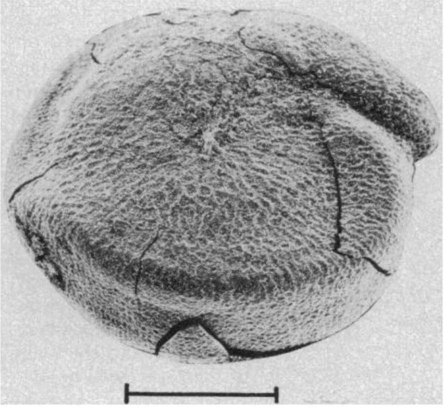

Fig. 1. Fruit 33 from the Russell Cave *Chenopodium berlandieri* assemblage, showing both the distinctive reticulate-alveolate dorsal pericarp patterning characteristic of section *Chenopodium* subsection *Cellulata* and the distinctive truncate margin associated with domestic varieties of this species. Scale bar, 500 μm. [Walter Brown]

Situated in a tributary valley of the middle Tennessee River in extreme northeast Alabama, Russell Cave has been the location of two major archeological excavations. A 1962 excavation (*14*) produced evidence of a 10-millennium long sequence of intermittent human occupation. In an earlier excavation (*15, 16*), the remains of a charred saucer-shaped basket containing carbonized *Chenopodium* fruits was uncovered against the northwest wall of the cave (*17*).

The basket, recently relocated in the uncataloged Russell Cave collections at the National Museum of Natural History, was found to consist of a thoroughly mixed and carbonized archeobotanical assemblage (61 g) that included wood, leaf, grass stem, and hickory nut fragments, as well as split-cane basket fragments (4.3 g) and approximately 50,000 *Chenopodium* fruits (19.1 g).

The date of a sample of the basket fragments, 1975 ± 55 years before present (B.P.) (S.I. 5502), compares favorably with the two radiocarbon dates from the Early Woodland layer D at Russell Cave (1995 ± 180 B.P. and 2100 ± 200 B.P.) (*14*); the "*Chenopodium* basket" thus represents the earliest known evidence for the deliberate storage of this plant species by prehistoric populations of the eastern woodlands.

Most of the *Chenopodium* fruits in the basket had ruptured during carbonization, but 581 unruptured specimens were found. Most ruptured and unruptured specimens retained their outer pericarp layer, and the distinctive reticulate-alveolate pericarp pattern present on the dorsal surface of the fruits (Fig. 1) allowed their assignment to section *Chenopodium* subsection *Cellulata* of the genus *Chenopodium*. On the basis of the geographical location of Russell Cave and the size range of the fruits, they can be further assigned to the species *Chenopodium berlandieri* (*18*).

It is the deliberate storage and subsequent spring planting of seed stock that marks the beginning of the process of domestication. This process also produces predictable changes in *Chenopodium* or any seed crop (*10*). The unruptured fruits from Russell Cave were examined for evidence of the five interrelated morphological changes that together make up the adaptive response by seed-bearing plants (*10*), including *Chenopodium* (*8, 11–13*), to the artificial environment created by human intervention (planting) in the life cycle of a plant. These morphological changes are (i) infructescence compaction and terminalization; (ii) loss of natural shatter mechanisms; (iii) uniform maturation of fruit; (iv) loss or reduction of germination dormancy; and (v) increased perisperm-endosperm food reserves for germination.

Since the infructescence fragments necessary to demonstrate the presence of the first three of these morphological characteristics (*8*) were not preserved in the Russell Cave assemblage, possible evidence for domestication was limited to indications of reduction in dormancy and increased seedling vitality. In wild or weedy populations of *Chenopodium*, mechanisms of germination dormancy prevent the premature germination of mature seeds that have been naturally dispersed and are present in the soil. Although there are a variety of chemical or physiological inhibitors that can delay germination in seeds, the most obvious block in the case of *Chenopodium* is the simple physical presence of a thick outer seed coat or testa. In addition to mechanically restricting the enlargement and germination of the embryo, such hard outer seed coats are largely impermeable to water and gases and serve to block the passage of external elements that are essential for embryo emergence and development.

Although the physical dormancy produced by such a thick outer seed coat is of obvious selective advantage in wild and weedy plants, it is nonadaptive in domestic crops unless it is of short duration, breaking down between harvest and planting time (*10*). Reduced dormancy in domesticates is often reflected either in a thinner outer seed coat, or even its complete loss, and such is the case with *Chenopodium* (*11*). Among the Mexican domesticates the "chia" variety of *C. berlandieri* ssp. *nuttalliae* retains a thin outer seed coat (Fig. 2); the "huazontle" variety lacks an outer seed coat entirely (*8*). Scanning electron microscope observation of 20 fruits from the Russell Cave collection indicated the presence of a thin outer seed coat comparable to that of "chia," with a mean thickness of 11 μm (range 6 to 16 μm) (Fig. 2). In comparison, 18 modern carbonized and uncarbonized fruits from the wild species *C. bushianum, C. berlandieri*, and *C. missouriense* were observed to have outer seed coats with a mean cross section of 47.6 μm (range 40 to 57 μm) (Fig. 2.). The Russell Cave fruits reflect a 76 percent reduction in testa thickness in comparison to modern wild varieties of *Chenopodium*.

Testa loss or reduction in testa thickness in domestic varieties of *Chenopodium* is accompanied by a change to a characteristic rectanguloid fruit cross section that is quite different from the biconvex, rounded, or equatorial-banded shapes of wild fruits (*8*). The flattening or truncation of the seed coat margin, which results in this rectanguloid fruit cross section (Fig. 1), is in turn associated with a round to ligulate shift in cross section of the cotyledons (embryonic leaves) adjacent to the fruit wall. Although embryo advancement to the ligulate-cotyledon stage before germination in domestic varieties of *Chenopodium* is probably linked to reduced germination dormancy (*8*), the change in fruit cross section also allows an increase in perisperm food supplies for seedling growth. This increase in internal fruit volume and perisperm may in turn reflect selective pressure for seedling vitality (*10*).

A convincing causal link between selective pressure for seedling vitality and an increase in internal fruit volume and perisperm food reserves is difficult to establish, however. Alternatively, this morphological change could be simply the by-product of a thinner testa and selective pressure for reduced dormancy, or it might be argued that it reflects deliberate selection for yield. It is worth noting, however, that the combined effect of these potential selective factors did not result in a universal increase in the external dimensions (margin diameter) of the domesticated forms of *Chenopodium* in Mexico and South America. Although some of the domesticated varieties (for example, *C. quinoa*) exhibit an increase in seed size comparable to that which documents the domestic status of sunflower and marsh elder in the eastern

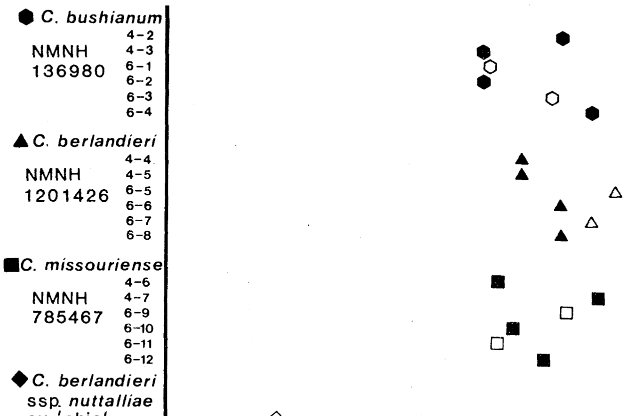

Fig. 2. The relative thickness of the outer seed coat of modern domesticated and wild varieties of *Chenopodium* compared with the Russell Cave *Chenopodium berlandieri* assemblage. Numbers along the vertical axis provide scanning electron micrograph specimen mount information. Fruits from modern wild eastern U.S. varieties (Missouri) were obtained from collections at the National Museum of Natural History, and fruits of the Mexican domesticate "chia" were provided by H. D. Wilson. A percentage of the modern specimens were carbonized to establish that the process of carbonization does not result in any significant reduction in the thickness of the outer seed coat.

woodlands (*19*), the Mexican domesticates and the Russell Cave fruits (*18*) fall within the size range of modern wild varieties of the genus. Both the Mexican domesticated forms of *Chenopodium* and the Russell Cave fruits, however, have a greater internal fruit volume and more perisperm than do wild fruits of the same diameter because of the shift to a rectanguloid cross section. A total of 387 Russell Cave *Chenopodium* fruits were sufficiently intact to enable observation of cross-section and margin configuration, with 353 (92 percent) having a rectanguloid cross section and truncate margin.

The Russell Cave *Chenopodium* assemblage exhibits a set of interrelated morphological characteristics that reflect domestication and establish the presence of a domestic variety of the species *Chenopodium berlandieri* within the garden plots of the eastern woodlands by 2000 years ago. Whether this early domesticate was introduced from Mexico or was the product of an independent process of domestication is not known.

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References and Notes

1. R. Yarnell, "Prehistoric plant foods and husbandry in eastern North America," paper presented at the 48th annual meeting of the Society for American Archaeology, Pittsburgh, 29 April 1983.
2. M. Kay, F. B. King, C. K. Robinson, *Am. Antiq.* **45**, 806 (1980).
3. N. Conard, D. Asch, N. Asch, D. Elmore, H. Grove, M. Rubin, J. Brown, M. Wiant, K. Farnsworth, T. Cook, *Nature (London)*, in press.
4. D. Asch and N. Asch, "A chronology for the development of prehistoric horticulture in west central Illinois," paper presented at the 47th annual meeting of the Society for American Archaeology, Minneapolis, 17 April 1982.
5. D. Asch and N. Asch, in *Cent. Am. Archeol. Contract Archeol. Program Rep. Invest.* **137** (1983).
6. S. Johannessen, in *American Bottom Archaeology*, C. Bareis and J. Porter, Eds. (Univ. of Illinois Press, Urbana, 1984).
7. D. Asch and N. Asch, *Mid-Cont. J. Archaeol.* **2**, 3 (1977).
8. H. D. Wilson, *Econ. Bot.* **35**, 233 (1981).
9. G. Fritz, *Am. Antig.* **49**, 558 (1984).
10. J. R. Harlan, J. M. J. de Wet, E. G. Price, *Evolution* **27**, 311 (1973).
11. H. D. Wilson and C. B. Heiser, Jr., *Am. J. Bot.* **66**, 198 (1979).
12. H. D. Wilson, *Syst. Bot.* **5**, 253 (1980).
13. ______, *ibid.* **6**, 253 (1981).
14. J. Griffin, *Pub. Archaeol.* **13** (No. 13) (1974).
15. C. Miller, *Natl. Geogr.* **110**, 542 (1956).
16. ______, *ibid.* **113**, 426 (1958).
17. ______, *South. Indian Stud.* **14**, 31 (1960).
18. Russell Cave is located south of the present-day range of *C. bushianum* and north of the known range of *C. berlandieri*. With a mean fruit diameter of 1.33 mm ($n = 525$; range, 1.0 to 1.8 mm, standard deviation 0.13), however, the Russell Cave assemblage compares favorably with *C. berlandieri* and not with the larger fruited *C. bushianum* (*7*). See Wilson (*12*) for a discussion of the probable conspecific nature of *C. bushianum* and *C. berlandieri*.
19. R. Yarnell, in *Univ. Mich. Mus. Anthropol. Anthropol. Pap.* **67** (1978), p. 289.

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Venus: Volcanism and Rift Formation in Beta Regio

Abstract. *A new high-resolution radar image of Beta Regio, a Venus highland area, confirms the presence of a major tectonic rift system and associated volcanic activity. The lack of identifiable impact craters, together with the apparent superposition of the Theia Mons volcanic structure on the rift system, suggest that at least some of the volcanic activity occurred in relatively recent geologic time. The presence of topographically similar highland areas elsewhere on Venus (Aphrodite Terra, Dali Chasma, and Diana Chasma) suggests that rifting and volcanism are significant processes on Venus.*

Among the terrestrial planets and satellites, Venus is the most like the earth in size and density and may provide important clues to planetary thermal and tectonic evolution (*1, 2*). The nature of the geologic processes that form and modify the surface of Venus are poorly known, however. The atmosphere of Venus precludes observations of the surface at visible wavelengths from orbit. Radar observations, however, have provided information about the general topography (*3, 4*) and more detailed images of parts of the surface (*5–7*). This information has revealed the presence of highland regions on Venus rising more than 1.5 km above mean planetary radius and comprising about 8 percent of the surface of the planet (*4*). Establishing the nature and origin of these highland regions is critical to deciphering the geologic history of the planet and to understanding the mechanisms of lithospheric heat transfer (*2*). We describe new high-resolution radar images of the Beta Regio highlands of Venus that show details of volcanic and tectonic features and provide insight into the formation of highlands on Venus.

Beta Regio is an oval-shaped highland region centered near 25°N latitude and 280° longitude. It extends for about 2500 km in a north-south direction and is approximately 2000 km wide, rising as high as 5 km above median radius (Fig. 1, a and b). Early radar observations of Venus from the earth (*6, 8*) revealed the presence of two radar-bright features in this region that were designated Beta (now called Theia) and Delta (now Rhea). Subsequent data revealed more details of these features (*5, 9, 10*) and provided topographic information, leading Saunders and Malin (*11*) to characterize Theia as an elevated, high-reflectivity region approximately 700 km across, with a summit region rising 10 km above its surroundings. In the center of the summit there was a low-reflectivity region, 60 to 90 km in diameter. Saunders and Malin interpreted Theia and Rhea to be large volcanic constructs similar to those of the Tharsis region of Mars. Additional images made from the earth at 10 km resolution (*12*) and Pioneer-Venus altimetry, roughness, and reflectivity measurements (*3, 4*) allowed further characterization. Masursky *et al.* (*4*) noted that Beta Regio has complexly varying radar brightness values, elevations, and root-mean-square slopes. The two irregularly shaped shieldlike features Theia and Rhea Montes dominate the topography (Fig. 1, a and b) and lie adjacent to a central north-south trending canyon (*13, 4*), which appears to be a northern extension of a complex disrupted region of en echelon (parallel but each offset to the front or rear) ridges and troughs south of Beta Regio. Masursky *et al.* (*4*) interpret the central Beta Regio trough to be a rift and Rhea and Theia Montes to be constructional volcanic features. McGill *et al.* (*14*) have drawn topographic analogies between Beta Regio and the East African rift system.

In August and September 1983, we obtained a high-resolution image (approximately 2 km radar resolution) (Fig. 1a) of central Beta Regio that reveals geologic details of Rhea and Theia Montes and the central chasma. The image was obtained with the 12.6-cm wavelength radar system at Arecibo Observatory in Puerto Rico. The image maps the backscatter cross section per unit area (surface reflectivity) with the angle at which the surface is illuminated by the incident radar wave varying across the image from approximately 44° to 52°. Scattering laws and the data acquisition and reduction techniques are described elsewhere (*5*). In this image, variations in brightness are mainly due to differences in small-scale (wavelength-size) surface roughness (bright, high values, and dark, low values), but variations in the surface dielectric constant also play a role. For some of the linear features in the region between Theia and Rhea Montes there is evidence for single-scatter quasispecular reflection indicating the presence of steep slopes.

The high-resolution image (Fig. 1a) shows four distinctive regions. Along the eastern side of the image are a series of parallel to subparallel bright linear features forming a zone 100 to 350 km in