

The domestication of *Helianthus annuus* L. (sunflower)

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Abstract All modern domesticated sunflowers can be traced to a single center of domestication in the interior mid-latitudes of eastern North America. The sunflower achenes and kernels recovered from six eastern North American sites predating 3000 B.P. that document the early history of this important crop plant are reanalyzed, and two major difficulties in the interpretation of archaeological sunflower specimens are addressed. First, achenes and kernels obtained from a modern wild sunflower population included in a prior genetic study because of its minimal likelihood for crop-wild gene flow, and its close genetic relationship to domesticated sunflowers, provide a new and more tightly drawn basis of comparison for distinguishing between wild and domesticated achene and kernel specimens recovered from archaeological contexts. Second, achenes and kernels from this modern wild baseline population were carbonized, allowing a direct comparison between carbonized archaeological specimens and a carbonized modern wild reference class, thereby avoiding the need for the various problematic shrinkage correction formulas that have been employed over the past half century. The need for further research on museum collections is underscored, and new research directions are identified.

Keywords Sunflower · *Helianthus annuus* · Domestication · Agriculture · Archaeobotany

Introduction

Recent genetic and archaeological research confirms that eastern North America was an independent center of plant domestication, with at least four indigenous seed-bearing species brought under domestication between 5,000 and 3,800 years ago: *Cucurbita pepo* L. var. *ovifera* (squash), *Helianthus annuus* L. (sunflower), *Iva annua* L. (marshelder), and *Chenopodium berlandieri* Moq. (chenopod) (Smith 2006a, 2011; Smith and Yarnell 2009; Blackman et al. 2011; Kistler and Shapiro 2011). Future genetic analysis of well preserved archaeological plant remains holds the promise of eventually documenting this domestication process in much greater detail by establishing the timing and sequence of appearance of various “domestication alleles” in these indigenous eastern North American crop plants (Doebly et al. 2006; Jaenicke-Després and Smith 2006; Blackman et al. 2011). Until such DNA research is carried out, however, our understanding of the early history of these four eastern domesticates rests on the recovery, documentation, and accurate dating of ancient seeds and other plant parts that differ from those produced by their wild ancestors in terms of exhibiting changes in morphology associated with deliberate human planting and harvesting of stored seed stock (Smith 2006b). The *Cucurbita* seeds recovered from the Phillips Spring site, the *Iva* achenes identified at the Napoleon Hollow site, and the *Helianthus* achenes reported from the Hayes site, for example, are all larger than seeds/fruits recovered from modern wild populations of the same species, while chenopod seeds from the Riverton and Newt Kash Hollow

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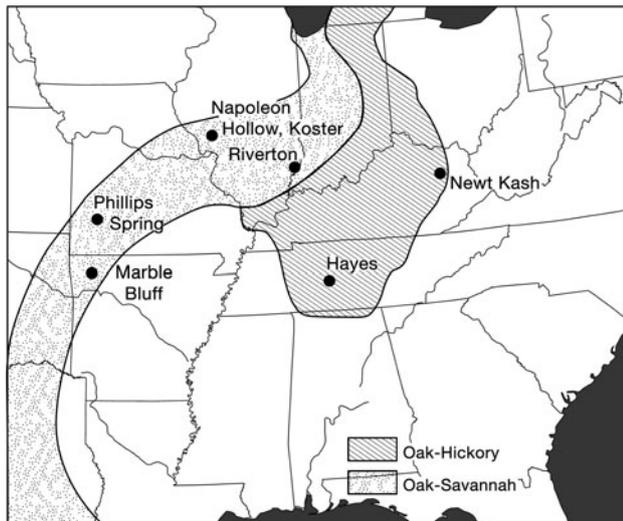


Fig. 1 The location of archaeological sites mentioned in the text

sites have thinner seed coats than their present-day wild relatives (Fig. 1). Both of these morphological changes (an increase in seed size and a reduction in seed coat thickness) reflect adaptive responses to seedbed selective pressure, and are clearly linked to the process of domestication (Smith 2006b).

Here I consider the currently available archaeological evidence for the initial domestication of one of these four eastern North American domesticates—*Helianthus annuus* L. (sunflower). Domesticated sunflowers, including archaeological specimens that fall outside the range of modern wild populations of *H. annuus* in terms of morphology (for example, larger flowering head or disk, achene, kernel) are designated as *H. annuus* var. *macrocarpus*. Two seed fragments recovered from the San Andres site in Tabasco, Mexico, far outside the modern range of distribution of *H. annuus*, have been claimed to provide evidence for the domestication of the sunflower (Lentz et al. 2001, 2008a, b). Genetic research has confirmed, however, that all modern domestic sunflowers have developed from wild ancestor populations in eastern North America (Blackman et al. 2011). As a result, if the two San Andres specimens were sunflower, which has been called into question, they would at most represent a second domestication event that subsequently failed (for a fuller discussion of the problematic nature of the San Andres specimens from a variety of perspectives, see Brown 2008; Heiser 2008a, b; Rieseberg and Burke 2008; Smith 2008).

Sunflower specimens identified as being from domesticated as opposed to wild plants were recovered from dry caves and rock-shelters in the Ozarks and in eastern Kentucky as early as the 1930s (Gilmore 1931), and by the mid-1940s Charles B. Heiser Jr. began his long-term consideration of this species and its domestication. Combining

available archaeological and early historical information with his research on modern *Helianthus* populations across North America, Heiser published a series of articles that included discussion of the necessary steps and the numerous assumptions and potential complications involved in any effort to differentiate between wild and domesticated specimens of *Helianthus* in the archaeological record (Heiser 1945, 1951, 1954, 1965a, 1965b, 1978, 1985). Over the past 60 years a number of other researchers, most notably Richard Yarnell (1978, 1981), have extended and refined various aspects of Heiser's basic research design for documenting domesticated *Helianthus* in the archaeological sites of eastern North America, and here I refer to and build upon the pioneering and prescient work of both Heiser and Yarnell.

Heiser's comprehensive and continent-wide consideration of modern wild *Helianthus* populations perfectly positioned him to address the most basic initial challenge facing anyone searching for evidence of domesticated *Helianthus* in the archaeological record—determining a *size standard for its wild progenitor*. By documenting the continental range of variation that existed in the size and shape of present-day wild and ruderal (weed) *Helianthus* achenes and heads, Heiser was able to define a solid, empirically-based general morphological profile for what ancient wild specimens should look like.

In developing the first comprehensive modern wild baseline of comparison necessary for the recognition of domesticated *Helianthus* in the archaeological record, Heiser also recognized a potential serious complication with his data set. The complication in question was the possibility of *introgression*—that some of the modern populations which he included in his comparative data base might not be truly wild, but rather may have been genetically and morphologically influenced (e.g. larger seeds) through cross pollination with nearby cultivated fields of domesticated sunflower.

Heiser also considered another complication involving the size of some archaeological sunflower specimens—their possible *shrinkage due to carbonization*. The dry caves and rockshelters of eastern North America, on the one hand, often yield abundant assemblages of desiccated and well-preserved plant remains that for the most part retain their original size and shape. In stark contrast, plant remains are much less commonly preserved in open-air sites unless they have been exposed to high heat from a fire and in anoxic conditions (the absence of air), resulting in carbonization or charring, and a reduction in size. In order to establish how much shrinkage occurred during carbonization, Heiser charred a total of 70 *Helianthus* achenes and observed a 10 % average loss in length and a 21 % average loss in width. Yarnell (1978) subsequently adopted Heiser's achene shrinkage values and also proposed shrinkage correction values for carbonized *Helianthus* achenes or

kernels (Yarnell 1978, p. 296). A number of subsequent *Helianthus* carbonization studies have been carried out since the pioneering efforts of Heiser and Yarnell (see Braadbaart et al. 2006; Braadbaart and Wright 2007), adding to a broader and rapidly expanding set of experiments on the general question of the effects of carbonization on archaeobotanical specimens.

Each of these three initial challenges addressed by Heiser: (1) establishing a size standard for wild sunflower; (2) addressing the question of introgression; and (3) correcting for carbonization due to shrinkage, are considered below, setting the stage for a reconsideration of the archaeological evidence for the timing and location of sunflower domestication in eastern North America.

Measuring modern sunflowers and the development of a morphological profile for the wild progenitor of *Helianthus annuus*

When the hard outer shell or pericarp of a *Helianthus* seed is still intact, the seed and shell together are technically defined as a dry indehiscent one-seeded fruit or achene (Heiser 1951, p. 432). The *Helianthus* achene (a seed or kernel and its intact surrounding shell or pericarp) (Fig. 2) has most often been the target of measurement studies, and for more than 60 years uncarbonized achene length and width measurements derived from modern free-living sunflowers have formed the standard baseline for distinguishing between wild and domesticated *Helianthus* specimens recovered from archaeological contexts. When uncarbonized *Helianthus* kernels (without shell) or carbonized *Helianthus* achenes, shells, or kernels are present in archaeobotanical assemblages, several conversion or correction formulas have been applied in order to estimate the size of the uncarbonized achenes they represent (see below).

Over the past three decades, numerous authors have employed an uncarbonized achene length value of 7.0 mm as marking a general boundary line separating individual achenes produced by wild plants from those representing domesticated plants (Heiser 1978, 1985; Yarnell 1978, 1993; Adair 1988; Crites 1993; Fritz 1997; Lentz et al. 2001; Smith 2006c; Bonzani et al. 2007, p. 74).

In addition, in 1981, Richard Yarnell first proposed multiplying achene length and width measurements ($L \times W$) to generate a “size index” value as “a reliable indication of achene size for purposes of comparison” (1981, p. 57). Following Yarnell, researchers have frequently employed $L \times W$ size index values in comparing *Helianthus* assemblages (Asch and Asch 1985, pp. 165–170; Adair 1988, p. 67; Lentz et al. 2001, p. 371; Bonzani et al. 2007, p. 74), with Lentz et al. (2001, p. 371) arguing that *Helianthus* size index values below 23 represent wild plants.



Fig. 2 The outer shell and seed of a 3,300 year-old *Helianthus* specimen from Newt Kash Shelter Kentucky (achene dimensions 9.3×3.7 mm)

A third standard of measurement for identifying domesticated *Helianthus* achene assemblages was added by Richard Yarnell in 1991 when he proposed “a mean length value of 6.0 mm as indicative of domestication in prehistoric sunflower sample populations” (personal communication to Gary Crites, cited in Crites 1993, p. 146).

All three of these proposed standards for distinguishing domesticated sunflower achenes in an archaeological context (individual uncarbonized achenes >7.0 mm; achene $L \times W$ size index >23 ; mean achene length value of an archaeobotanical assemblage >6.0 mm) can be traced back to a single graph appearing in Charles Heiser’s classic article “Variation and subspeciation in the common sunflower, *Helianthus annuus*” (Heiser 1954, p. 295, Fig. 3). The scatter plot graph in question (redrawn here in Fig. 3), displays mean achene length and width values for 65 free-living *Helianthus* populations distributed throughout most of the range of the species. The 65 sample populations were divided into three geographical groupings:

- (1) Western North America, from southern Canada to northern Mexico (*H. annuus* ssp. *lenticularis*), with the average achene length for 27 populations ranging from 4.0 to 5.5 mm;
- (2) Eastern Texas (*H. annuus* ssp. *texanus*), with average achene length values for 11 populations ranging from 3.3 to 5.0 mm; and

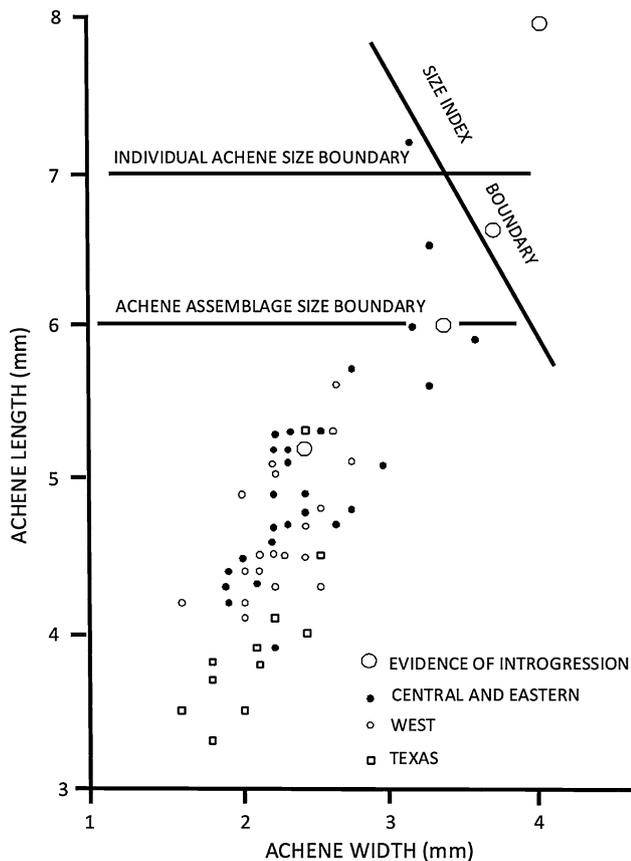


Fig. 3 Average length and width of *Helianthus annuus* achenes collected from 65 free-living populations in three regions of North America: West (open circles—27 populations); Central and Eastern (closed circles—27 populations) and Texas (open squares—11 populations). Large open circles exhibit evidence of introgression with cultivated *Helianthus* (after Heiser 1954, Fig. 3)

- (3) The central and eastern United States extending into south-central and eastern Canada (*H. annuus* ssp. *annuus*), with 27 populations having average achene length values ranging from 4.0 to 7.0 mm (Heiser 1954, pp. 299–300)

Heiser concluded that the wild *Helianthus* populations of the central and eastern United States were ancestral to the domesticated *Helianthus* (1954, p. 303), and the upper end of the average achene length size range for this region (ca. 7.2 mm) was subsequently used to identify 7.0 mm as providing a reasonable minimum length standard for identifying individual achenes recovered from an archaeological context as coming from a domesticated plant (Fig. 3).

In addition, Heiser's placement of the 65 population data points along length and width measurement axes provided the clear template for Yarnell's development in 1981 of a $L \times W$ size index approach to comparing *Helianthus* achenes, as well as the assertion by

Lentz et al. (2001) that a $L \times W$ size index value of <23 represents wild plants (Fig. 3). Finally, the clustering of *Helianthus* populations below the 6.0 mm achene length line in Heiser's graph was also quite likely the basis for Yarnell's proposal in 1993 that archaeological *Helianthus* assemblages with a mean length >6.0 mm could be identified as domesticated. Heiser's (1954) publication has thus provided, for more than a half century, the standards by which archaeologists identify domesticated sunflower achenes in archaeobotanical assemblages.

Along with achenes, *Helianthus* heads or disks recovered from archaeological contexts in eastern North America also have the potential to provide information regarding the initial domestication and early history of cultivated *H. annuus*, even though only about two dozen partial or complete heads have been reported. Heiser's (1954) study provides information regarding the size (diameter) of *Helianthus* heads or disks in the populations he studied, and his stated size range of 30–50 mm diameter for the central and eastern populations (*H. annuus* ssp. *annuus*) (Heiser 1954, p. 300, 1978, pp. 44–45) has also been adopted as providing a general guideline for distinguishing between wild and domesticated specimens in the archaeological record (Bonzani et al. 2007).

The problem of hybridization in establishing a modern wild reference class

In his landmark study of geographical variation in wild *Helianthus* populations, Heiser (1954) discussed at length the possibility of hybridization between domesticated and wild *Helianthus* and the resultant occurrence of domestic characteristics in some free-living plants. Four free-living populations from western North America that exhibited morphological characteristics of domesticated plants (e.g. large achenes and disks, and high ray number) were selected as clear but far from unique examples of such hybridization: "These four populations have been selected for special comment, but it seems likely that such hybridization may have influenced considerably the plants in other parts of the west" (Heiser 1954, p. 297). Three of the four western populations selected by Heiser as the best examples of hybridization in his study yielded achenes that were far larger than those collected from other western populations, and all four were identified in his achene size scatter plot by larger circles (Fig. 3).

Heiser's concerns regarding hybridization between wild and domesticated sunflowers and the resultant changes in morphology were not, however, limited to the western United States (Heiser 1954, p. 305, 1965b, p. 395, 1978, 1985, p. 58). He concluded that "hybridization with the cultivated *Helianthus* in the east may influence the

variation pattern in this area”, and identified free-living populations in Minnesota, North Carolina, Indiana, and Missouri as possibly being of hybrid origin (Heiser 1954, p. 297). Importantly, Heiser explicitly recognized that the hybrid origin of some populations in the east, particularly in regard to ruderal or weed stands in anthropogenic settings, could have considerable time depth (Heiser 1954, p. 297). The four to six eastern *Helianthus* populations shown in his Fig. 3 that are comparable to the four western hybrid samples singled out for discussion by Heiser in terms of larger achene size values probably represent the hybrid candidate populations he identified and discussed in the text.

Richard Yarnell (1978, p. 290) also acknowledged the problem of hybridization between modern wild and domesticated *Helianthus* populations in the east, and the likelihood that the large ruderal forms growing in disturbed habitat situations represented “feral descendants of early domesticated forms”. Similarly, Asch and Asch (1985, p. 169) recognized the possible role of hybridization with cultivated *Helianthus* in the east in producing the “long tails of occasional populations from which achenes were recorded that were much larger than the model size”.

These eastern free-living ruderal *Helianthus* populations, and the large-achene wild-cultivated hybrid plants they contained, presented a clearly acknowledged complication in the development of a modern wild *Helianthus* reference class. Since they were difficult to unequivocally distinguish from wild *Helianthus* populations in the east, Heiser and Yarnell had little choice but to include the probable hybrid samples in an initial reference class, while also recognizing that their inclusion would result in an over-estimation of the upper size limit of achenes produced by wild ancestor *Helianthus* populations. By establishing the initial “wild-domesticated” boundaries (7.0 mm for individual achenes, 6.0 mm for achene assemblages) along the upper edge of all the modern eastern populations studied by Heiser, they defined an appropriately conservative and substantially buffered standard for assigning domesticated status to archaeological specimens. With the exception of the four to six eastern outlier populations included in Heiser’s study, all 21–23 of the other eastern samples, like the 23 western non-hybrid samples, fall below the 5.5 mm in length maximum that Heiser established for the western (*H. lenticularis*) populations (Heiser 1954, p. 299), providing a full 1.5 mm buffer between the largest probable wild population achene length value and the minimum boundary for assigning domesticated status to *Helianthus* achenes recovered from an archaeological context (Fig. 3). Under these conservative guidelines, any archaeological achenes more than 7.0 mm in length could be identified with a high level of confidence as representing a domesticated crop plant, since they would not only be

more than 25 % larger than achenes from probable wild plants, but also larger than achenes produced by apparently introgressed populations whose genetic history likely involved multiple backcrossing events between cultivated and wild plants over multiple generations.

The concerns expressed by Heiser, Yarnell, and others regarding the likely hybrid nature of present-day eastern sunflower populations were well founded, based on the considerable research carried out since the early 1990s on gene flow dynamics between cultivated sunflower and wild *H. annuus*. These studies have shown that introgression from cultivated to wild sunflower populations appears to occur with little impediment, at substantial rates, and over considerable distances (Ellstrand 2003, pp. 98–99). Experimental planting of wild sunflowers at various distances around fields of cultivated sunflowers has detected spontaneous hybridization at distances of up to 1,000 m (Arias and Rieseberg 1994). A similar study documented crop specific markers persisting in a wild *Helianthus* population for five generations following a single season of exposure to a nearby crop plantation (Whitton et al. 1997). Another study looked at three wild *H. annuus* populations that had long-term contact (20–40 years) with cultivated *Helianthus*, and documented an average overall frequency of cultivar markers of more than 35 %, with every individual tested exhibiting at least one cultivar-specific allele (Linder et al. 1998; Ellstrand 2003, p. 100). A predictive simulation study of the impact of hybridization between cultivated and wild *Helianthus* further indicated that in situations of continued exposure to domesticated crops, wild *Helianthus* can be driven to extinction (all plants exhibit hybrid ancestry) in a relatively few number of generations (Wolf et al. 2001; Ellstrand 2003, pp. 190–191). Fortunately, at the same time that these hybridization studies have on the one hand confirmed substantial gene flow between cultivated and wild *Helianthus* populations, parallel genetic research projects have also succeeded in identifying present-day wild *Helianthus* populations that appear to be minimally affected by hybridization with domesticated plants.

Genetic research and the development of a more tightly defined reference class

A series of genetic studies (Harter et al. 2004; Rieseberg and Harter 2006; Wills and Burke 2006; Blackman et al. 2011) sampled more than 20 free-living populations from throughout the present-day continental range of *H. annuus*, focusing on “large populations from natural sites that were far from cultivated fields to minimize the potential for crop-wild gene flow” (Rieseberg and Harter 2006, p. 37). These studies identified an “east-central United States local cluster” encompassing *Helianthus* populations sampled in

Iowa, Missouri, and Oklahoma (along with a geographical outlier stand in Tennessee) as having the closest genetic relationship with domesticated *Helianthus* (Rieseberg and Harter 2006, p. 41), confirming Heiser's identification of a single origin for all domesticated *Helianthus* from wild ancestor populations in the east-central United States. High levels of gene flow between populations in this east-central United States area, however, did not allow a more precise spatial identification of the most likely progenitor population. In comparison to the broad geographical scope of Heiser's original survey of modern free-living *H. annuus*, the sunflower populations of this Iowa—Missouri—eastern Oklahoma core area (Rieseberg and Harter 2006, Fig. 2.3 and ESM 1) provide a second, more narrowly drawn, wild reference class for distinguishing between wild and domesticated *Helianthus* in the archaeological record.

The initial sampling of these modern *Helianthus* populations for genetic analysis by Loren Rieseberg and his colleagues involved taking leaf cuttings rather than collecting achenes. Eric Baack, however, returned to one of the east-central United States populations; the DeSoto National Wildlife Refuge population in Iowa, in 2007 (ESM 1), and collected 92 *Helianthus* heads and associated achenes, each from a separate plant. This collection, which represents about half of the ca. 200 plants scattered over a 400 by 100 m area (ESM 2), was in turn provided to me for study by Nolan Kane.

The 92 dry *Helianthus* heads collected from the DeSoto population have a mean disk diameter after drying of 24 mm, with a range of 17–33 mm (Fig. 4). In order to capture the full range of achene size variation within the DeSoto *Helianthus* population, a sample of 25 achenes was initially drawn from each of 13 heads (ESM 3). An additional 25 achenes were subsequently drawn from each of three of the largest heads for a kernel carbonization study (see below), bringing the total of measured achenes to 350 (Fig. 5a, b). The 13 *Helianthus* heads that contributed achenes for measurement ranged in diameter from 18 to 33 mm, and the six largest heads in the population were all sampled in an effort to ensure representation of the largest achenes occurring in the DeSoto stand.

In comparing these DeSoto population disk and achene measurements with similar summary statistics on *Helianthus* populations reported by Heiser (1954), it is important to note that his continent-wide study of the common sunflower was designed to result in a “fairly accurate sample of the variability of the species as a whole” (Heiser 1954, p. 287). As a result it focused on documenting morphological diversity within and between a large number of sunflower populations comprising regionally distinct subspecies over a vast geographical area. Even though he was not specifically targeting for documentation those specific free-living *Helianthus* populations that represented the

most likely modern descendants of the wild progenitor of the species, his broader-scale data sets have provided a general framework for efforts to document the initial domestication of the species in eastern North America. They also represent a solid background for discussion of the DeSoto population, which provides a higher resolution modern morphological profile for the wild ancestor of *H. annuus* and a more accurate baseline of comparison for distinguishing between wild and domesticated *Helianthus* remains in the archaeological record.

With a range of 17–33 mm, and a mean disk diameter of 24 mm, for example, the DeSoto population *Helianthus* heads fall mostly outside of the 30–50 mm size range Heiser documented for *Helianthus* populations in the central-eastern United States. They do, however, compare favourably with the disk size range reported for the smaller western (*H. annuus* ssp. *lenticularis* (20–35 mm) and Texas (*H. annuus* ssp. *texanus* (21–30 mm) subspecies described by (Heiser 1954, pp. 288–289, 299–300). The smaller size of the DeSoto population disks when compared to the central and eastern populations sampled by Heiser could be due to several factors. Gene flow between fields of cultivated *Helianthus* and free-living plants may have resulted in larger average disk size in the populations included in his study. Heiser's disk measurements were also taken during the growing season (“measurements of disk diameters were made on terminal heads on the morning of the anthesis of the outermost row of disk flowers” Heiser 1954, p. 289), whereas the DeSoto population disks were measured after drying, and may have experienced an associated reduction in size. The DeSoto population disks thus provide an improved wild progenitor proxy for identifying domesticated *Helianthus* specimens archaeologically, both because they are from a single free-living population identified as being genetically close to domesticated *Helianthus* and minimally impacted by crop-wild gene flow, and because like archaeological specimens, they were fully desiccated when measured.

In contrast to the DeSoto disks, the sample of 350 achenes from the DeSoto *Helianthus* population provided length and width measurements that are generally comparable with the central and eastern United States populations described by Heiser. The mean achene length (4.97 mm) and width (2.34 mm) values for the DeSoto population cluster comfortably within the scatterplot of average achene length and width values reported for the central and eastern populations (ESM 4). These mean achene length and width values for the DeSoto population, along with the upper end of the DeSoto achene size range values (6.1 mm length, 3.0 mm width) also provide additional support for the role of gene flow from domesticates in contributing to the larger size of both disks and achenes in some of the central and eastern populations included in Heiser's study.

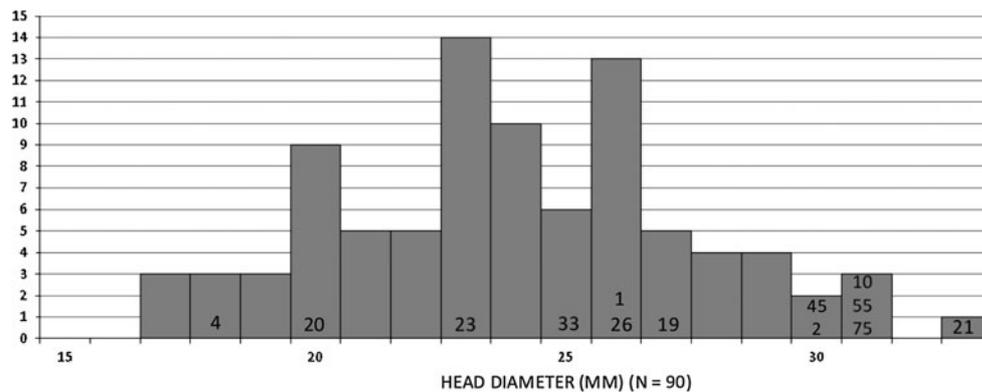


Fig. 4 *Helianthus* head measurements. Histogram showing the maximum diameter of 90 *Helianthus* heads or disks, each from a different plant, collected by Eric Baack from the DeSoto Wildlife Refuge population of ca. 200 plants scattered over a 400 × 100 m

area. The numbers shown within the histogram columns identify the 13 heads selected for sampling for achene length and width measurements. Twenty five achenes were taken from each of the 13 heads selected, providing an initial sample of 325

Carbonization

In contrast to the dry caves and rockshelters of eastern North America, which have yielded desiccated and well-preserved *Helianthus* achenes and seeds that for the most part retain their original size and shape, *Helianthus* specimens are rarely recovered from open air sites in the region unless they were exposed to high heat from a fire in anoxic conditions (an absence of air). While such exposure increases the probability of preservation and recovery, it also results in a reduction in size due to carbonization or charring. There is a long history of experiments carried out to determine seed size shrinkage rates due to carbonization, with Neuweiler's (1905) documentation of an 8 % shrinkage rate in the length of linseeds being one of the first to actually measure and report changes in seed dimensions resulting from charring. Helbæk's (1952) research on crab-apple seeds in turn, appears to have been the first carbonization study to record time and temperature information, with Heiser's similar study of shrinkage of *Helianthus* achenes due to carbonization reported the following year:

"... achenes of a number of modern and Indian varieties were artificially charred by placing them in an oven for 3 h at 370 °C. Ten achenes each of seven varieties were used. The individual achenes were measured before and after charring and on the average it was found that charred achenes were 90 % of their original length with a range of 87–94 % for the seven samples. Similarly it was found that the width of the charred achenes was 79 % of the original value and the thickness 85 %. These averages have been used in an attempt to postulate the original measurements of the archaeological achenes before charring took place." (from a 1953 unpublished manuscript by Charles B. Heiser Jr. entitled "The archaeological record of the cultivated sunflower with remarks concerning the origin of Indian agriculture in eastern North America").

In a subsequent 1978 published account a typographical error unfortunately reported that the carbonized achenes were 85 % as wide as uncarbonized ones (the correct value for carbonized achene width was 79 %. The 85 % value referred to achene thickness). "To determine the loss in charring so that comparisons could be made with uncharred achenes, 10 achenes each from seven different varieties were artificially charred, and it was found that on average the charred achenes were 90 % as long and 85 % [sic] as wide as the uncharred ones". (Heiser 1978, p. 48).

Yarnell (1978) subsequently adopted Heiser's achene shrinkage values and also proposed shrinkage correction values for carbonized sunflower kernels or seeds, proposing that in order to estimate original uncarbonized achene size, carbonized achene length and width values should be increased by 11 and 27 % respectively, and carbonized seed or kernel length and width should be increased by 30 and 45 % (Yarnell 1978, p. 296).

Following the pioneering experiments by Helbæk and Heiser, carbonization studies that control for time and temperature have been carried out on a range of different plant materials, including, most notably, the study by Braadbaart and Wright (2007) that considered shrinkage due to carbonization in *H. annuus*. They selected three different varieties of cultivated *Helianthus* for study, with samples of 100 achenes of each yielding average pre-carbonization length and width values of 10.3 × 4.85 mm (Hopi Black Dye), 11.51 × 8.3 mm (Apache Brown), and 11.95 × 6.53 mm (Arikara) (Braadbaart and Wright 2007, p. 139). Samples of 10 achenes of each variety were introduced into a tube oven under a constant flow of nitrogen to produce anoxic conditions, and both immediate and gradual exposure to three target temperature levels were investigated: 310, 440, and 600 °C. Achene shrinkage rates for all three varieties of *Helianthus* tested increased dramatically up to 370–400 °C, and then increased very

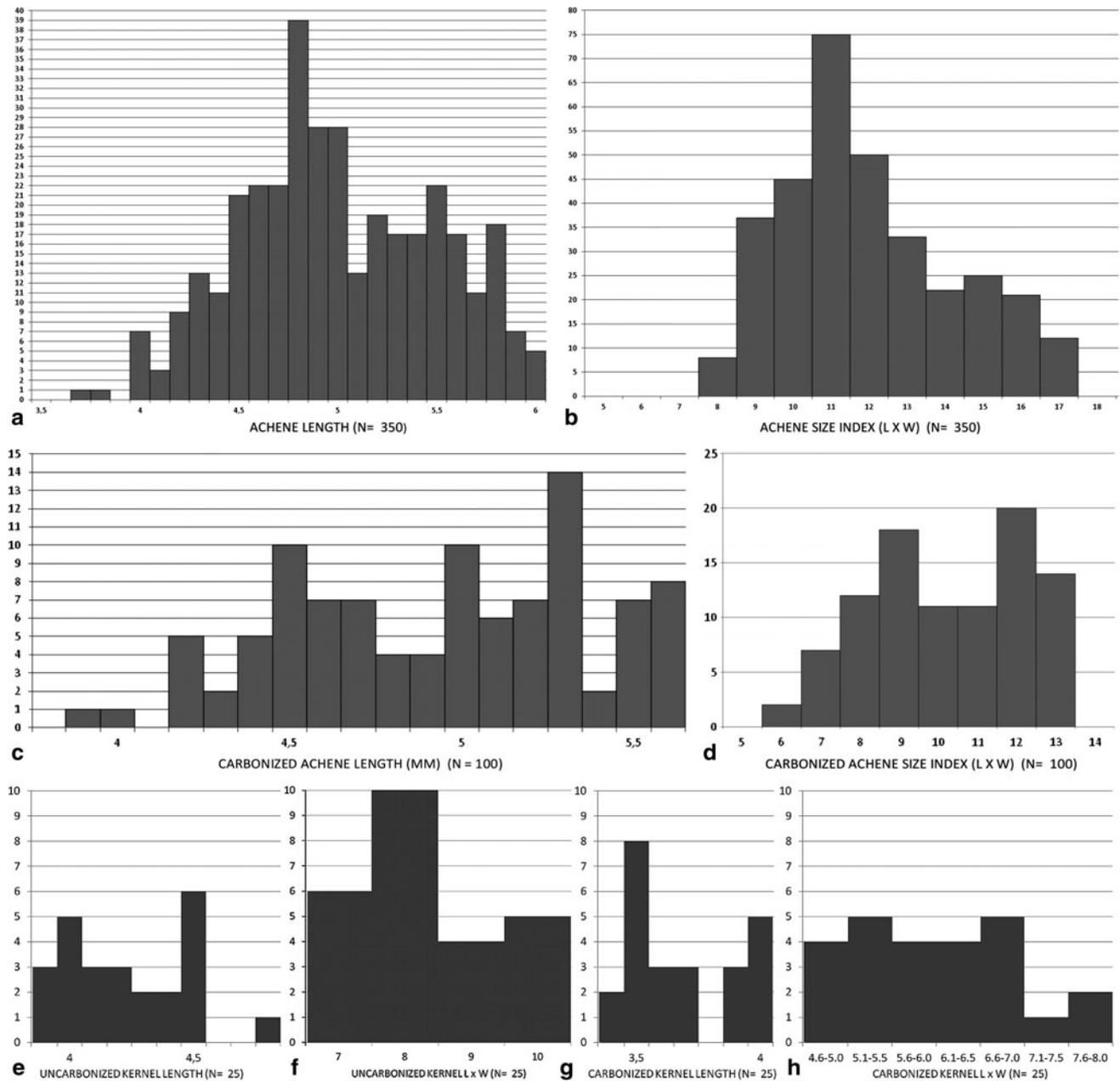


Fig. 5 Histogram of DeSoto *Helianthus* population achene measurements (mm): **a** length; **b** size index (L × W); **c** carbonized achene length; **d** carbonized achene size index (L × W); **e** uncarbonized

kernel length; **f** uncarbonized kernel size index; **g** carbonized kernel length; **h** carbonized kernel size index (L × W)

little if at all, between 400 and 600 °C, with length values shrinking by 12–22 % and width values by 21–28 % (Braadbaart and Wright 2007, p. 147). Interestingly, the shrinkage values documented for these three varieties of sunflower between 370 and 410 °C (ca. 8–18 % in length and ca. 21–24 % in width) compare quite well with the values obtained by Heiser in his carbonization study involving 10 achenes each of seven varieties heated at 370 °C for 3 h (a 6–13 % average reduction in length and a 21 % average reduction in width).

By heating *Helianthus* achenes in a carefully controlled laboratory setting, Braadbaart and Wright show how variation in the time of exposure, level, and rate of increase in temperature (heat-source related variables) significantly influence the degree of shrinkage due to carbonization, and convincingly demonstrate the problematic nature of employing a single correction factor in estimating the pre-carbonization dimensions of a charred *Helianthus* achene (Braadbaart and Wright 2007, p. 137). Their study also underscores how inherent differences between the achenes

of different *Helianthus* varieties (sample-related variables) may influence shrinkage rates, and they specifically mention the need to gain a better understanding of the role of oil and water content in determining size reduction due to carbonization (Braadbaart and Wright 2007, p. 142).

The three varieties they included in their study appear to have been selected in an effort to minimize the influence of sample-related variables such as oil content, since all were traditional land races (Hopi Black Dye, Apache Brown, Arikara) rather than commercially “improved” varieties. Although these traditional land races were all about the same length prior to carbonization (mean length values of 10.3, 11.5, 11.9 mm), however, consistently different shrinkage rates for the three were observed throughout the temperature range studied (Braadbaart and Wright 2007, Fig. 5a, b). This documentation of consistent differences in shrinkage rates between traditional land races of modern cultivated *Helianthus*, which reasonably could be expected to provide the closest match in terms of chemical composition with *Helianthus* represented in archaeological contexts, underscores the problematic aspects of employing modern cultivated *Helianthus* varieties in carbonization experiments designed to estimate shrinkage in ancient sunflower achenes.

The DeSoto population of modern wild *Helianthus* provides an alternative approach to addressing the problem of shrinkage of archaeological *Helianthus* specimens due to carbonization that avoids this complication of not being able to control sample-related variables. Rather than attempting to estimate the pre-carbonization size of ancient specimens in order to then compare them to a modern uncarbonized wild reference class, a sample of DeSoto population specimens, when carbonized, provides an alternative wild reference class to which carbonized archaeological achenes can be directly compared.

A total of 100 achenes from the DeSoto population were selected for carbonization, with 25 taken from each of four disks that ranged in size from 26 to 31 mm (Fig. 4, ESM 3). Achenes were placed in an electric muffle furnace and the temperature was then raised to, and maintained at, a temperature of 400 °C for a period of 2 h. Within the furnace, the achenes were contained in a ceramic vessel between two layers of powdered carbon in an oxygen-deficient environment (Freeburg 2002). Observed shrinkage rates for the DeSoto achenes were considerably lower than those documented for modern cultivated *Helianthus* varieties by either Heiser or Braadbaart and Wright, with mean achene length reduced by only 2–12 % versus 12–22 %, and width by 4–26 % vs. 22–28 % (ESM 5, 6). The much lower shrinkage rate for the DeSoto achenes, as well as the smaller standard deviation values of the DeSoto shrinkage curves could be explained in terms of lower

levels of components that contribute to shrinkage during carbonization in the achenes of wild *Helianthus*, as well as stronger selective control over the chemical composition of the achenes of wild populations. The DeSoto shrinkage rates also can be considered as conservative, in that a temperature above the 400 °C level used in carbonizing the achenes could potentially result in additional size reduction, a possibility that should be explored in future carbonization experiments employing achenes from wild *Helianthus* populations.

The length size distribution for the DeSoto *Helianthus* achenes after carbonization is shown in Fig. 5c, while Fig. 5d shows their size index distribution (length × width). Together, these two curves offer a new modern wild baseline of comparison for considering whether carbonized archaeological achene specimens represent the harvesting of wild plants or the cultivation of a domesticated crop.

In order to consider shrinkage rates for *Helianthus* kernels as opposed to achenes, a total of 25 achenes were selected from three of the largest DeSoto heads (ESM 7). Ranging in length from 4.8 to 5.9 mm, the 25 achenes were cut open and the kernels extracted. With lengths ranging from 3.9 to 4.8 mm (Figs. 5e, f), the kernels were then carbonized, following the same process that was employed for the DeSoto population achenes. The DeSoto kernels averaged a 12.1 % reduction in length due to carbonization (range: 10–16 %) (ESM 7). Yarnell (1978, p. 296) proposed multiplying carbonized kernel length values by 1.3 in order to approximate uncarbonized achene length values. The present study, however, indicates multiplier values of 1.35–1.61.

The length size distribution for the DeSoto *Helianthus* kernels after carbonization is shown in Fig. 5g, while Fig. 5h shows their size index distribution (length × width). Together, these two curves provide a modern wild baseline of comparison for considering whether carbonized archaeological kernel specimens represent the harvesting of wild plants or the cultivation of a domesticated crop.

Identifying domesticated *Helianthus* in the archaeological record

Distinguishing between the disks, achenes, and kernels of wild and domesticated *Helianthus* in the archaeological record, and documenting the early history of this important crop plant in eastern North America, including where and when it was first domesticated, involves a straightforward comparison of archaeological specimens with a modern wild reference class. If the archaeological specimens are larger in size than the modern reference class disks, achenes, or kernels from wild populations such as the DeSoto assemblage described here, then an argument can be made

that they are from domesticated plants, with the size increase reflecting either deliberate human selection for larger seeds and heads, or the automatic response of the plants to the new selective pressures associated with human planting and harvesting of stored seed stock that are part of the adaptive syndrome of domestication (Smith 2006b).

When compared to the disks collected from the DeSoto wild population in terms of diameter, for example, the much larger size of many of the sunflower disks recovered from archaeological contexts in eastern North America allows them to be confidently identified as representing domesticated plants (Fig. 6). Sunflower disks intact enough to provide diameter measurements have only rarely been recovered from archaeological sites in eastern North America, however, with a total of only 18 measurable specimens from four dry rock shelters reported to date (Heiser 1978; Fritz 1986; Bonzani et al. 2007). Although none of these disks have yet been described in detail or directly dated, the specimens from the Eden's Bluff and Montgomery 4 sites in the western Ozarks are likely less than 2,000 years old, given their large size (more than two to five times larger than the DeSoto disks). The smaller Newt Kash and Alred specimens may be older, and should be a future focus of research and dating. Although the absence of any ceramics or maize at Alred could indicate an early occupation, a radiocarbon date of 1600 ± 75 B.P. (β 14590) from the site (Fritz 1986) suggests that the three Alred disks may also post-date 2000 B.P. Given the remarkable spiral phyllotactic patterning reflecting the Fibonacci sequence that is evident on sunflower disks, it may also be possible to estimate disk diameter from fragmentary remains of disks recovered from dry rockshelter sites in the Ozarks and eastern Kentucky (Bonzani et al. 2007).

In developing an argument for the presence of a domesticated crop plant based on an increase in seed size or other morphological changes associated with domestication (Smith 2006b), the relative strength of the supporting argument increases with the number of such specimens that are found together in an archaeological site. The discovery of numerous "larger than wild" seeds in a pit or other storage context, for example, provides a stronger argument for the presence of a domesticate than would the recovery of a single specimen that exhibited morphology that was distinct from that of seeds from wild plants (e.g. larger size, thinner seed coat). Large quantities of *Chenopodium berlandieri* recovered from storage pits in Russell Cave Alabama, and Ash Cave Ohio, that exhibited a seed coat much thinner than modern wild populations of the species, for example, provided compelling evidence for cultivation of a domesticated crop plant rather than the harvesting of wild stands (Smith 2006c).

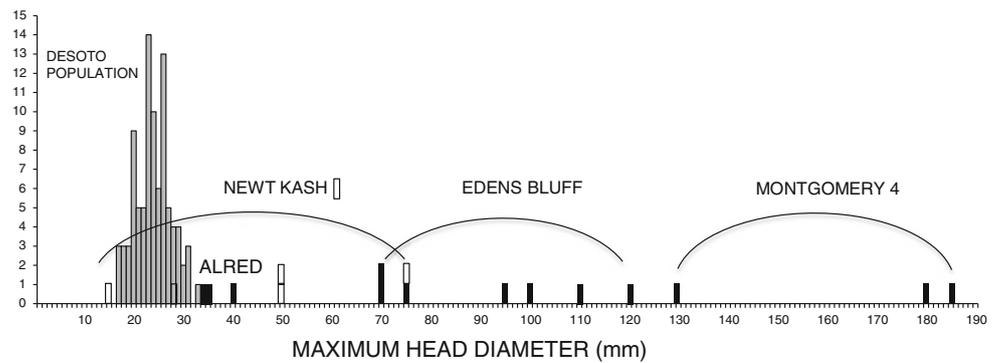
Marble Bluff

The Marble Bluff site (3Se1) in the Arkansas Ozarks provides just such an opportunity to develop a strong supporting argument for the early cultivation of domesticated sunflower in eastern North America, based on the recovery of a large number of sunflower achenes from a storage context. Marble Bluff is a 7 m wide habitation zone that extends for about 120 m along a west to southwest facing overhanging bluff located just above Mill Creek, a tributary of the Buffalo River, which in turn flows into the White River in Searcy County, Arkansas (Fig. 1) (Fritz 1986, p. 11, 24, 27, 1994, 1997). Excavation by a University of Arkansas crew in 1934 exposed a boxed-in crevice in the back wall of the shelter that is thought to have served as a storage place for seed stock (ESM 8) (Fritz 1997). Along with a variety of wooden, shell, and antler artifacts, the crevice contained the carbonized remains of five woven bags containing seeds, as well as an "unbagged" deposit of seeds estimated to have a volume of one gallon (Fritz 1997, p. 45). Three of the bags located adjacent to each other contained *Chenopodium berlandieri* (ESM 8, catalogue numbers 340, 341, 344), while the fourth and fifth bags, placed a few feet away, contained *Iva annua* (ESM 8, catalogue number 347), and the seeds of both *Cucurbita pepo* and *Helianthus annuus* (ESM 8, catalogue number 345). In contrast to the seed storage bags, which contained the seeds of only one or two domesticated crop plants, the one gallon unbagged deposit (ESM 8, catalogue number 327) contained a much wider range of species, and may have been meant for future consumption rather than spring planting (Fritz 1997, p. 51). Small sample AMS radiocarbon dates on *Iva*, *Ambrosia*, and *Chenopodium* seeds from two of the bags and the one-gallon seed deposit yielded very similar age determinations (ESM 8) indicating that the crevice quite likely represented a single storage event (Fritz 1997, p. 48).

In Gayle Fritz's broad-ranging consideration of archaeobotanical assemblages from Ozark rock shelter sites (Fritz 1986), length and width measurements were reported for a total of 73 *Helianthus* specimens from the Marble Bluff storage crevice (39 achenes from storage bag 345 and 34 achenes and 39 seeds or kernels from the unbagged deposit—327). In her subsequent study of the crop plants stored in the Marble Bluff crevice, she included 19 achenes from storage bag 345 and 15 achenes and 24 kernels from the unbagged deposit in her analysis (Fritz 1997, p. 55). Fritz provided a compelling case for the domesticated status of the Marble Bluff *Helianthus* specimens.

For this study, the *Helianthus* specimens sorted by Fritz from the unbagged deposit (catalogue number 327) from the Marble Bluff storage crevice were re-measured, and the carefully curated one gallon of unsorted material from the

Fig. 6 Histogram of archaeological *Helianthus* head dimensions, compared to the modern wild DeSoto population



unbagged deposit was also re-examined in an effort to identify additional measurable *Helianthus* achenes. During this re-examination of the catalogue number 327 unsorted material from the Marble Bluff storage crevice more than 100 small carbonized cordage fragments were identified, suggesting that there may have originally been a storage bag present. *Iva* and *Ambrosia* specimens were also observed in the unsorted matrix and several dozen examples of *Chenopodium* or *Ambrosia* seeds that had been fused to *Helianthus* achenes during carbonization of the deposit were noted.

The *Helianthus* specimens previously sorted by Fritz from the unbagged crevice deposit provided 41 intact achenes for which length and width measurements could be obtained, and the unsorted matrix from the same deposit yielded an additional 218 intact *Helianthus* achenes (ESM 9). The length and width measurements for this total sample of 259 carbonized sunflower achenes are given in ESM 10. ESM 11 shows the length and width values obtained on the Marble Bluff *Helianthus* achene assemblage, and Fig. 7a, b compare the achene length and achene size index values for the Marble Bluff assemblage with those obtained on a sample of 100 carbonized achenes from the modern wild DeSoto population.

As shown in Fig. 7a, b, the vast majority (97 %) of the Marble Bluff *Helianthus* achenes are larger than any of the carbonized achenes from the modern wild DeSoto population in terms of both length and size index ($L \times W$) measurements, providing strong evidence that the Marble Bluff archaeological assemblage represents the harvest from cultivation of a domesticated crop plant in the Arkansas Ozarks at about 3000 B.P.

Using the large Marble Bluff achene assemblage as a solid vantage point for considering other specimens recovered from archaeological contexts in eastern North America that may represent evidence of domesticated sunflower, we can look back in time at a total of 19 *Helianthus* specimens that have been securely dated to earlier than 3000 B.P. This set of 19 achenes and kernels provides a temporal series of small sample glimpses of potentially domesticated *Helianthus* at 3300 B.P. (Newt Kash), 3800

B.P. (Riverton), 4400 B.P. (Napoleon Hollow), 4800 B.P. (Hayes), and 6000–8500 B.P. (Koster) (Fig. 1, Table 1).

Newt Kash Hollow

The uncarbonized *Helianthus* achene and seed or kernel shown in Fig. 2, recovered from an undocumented context at the Newt Kash Hollow rock shelter in eastern Kentucky, has been directly dated to 3300 B.P. (Table 1). Measuring 9.3 mm in length by 3.7 mm in width, the Newt Kash achene falls substantially outside the size range of the DeSoto population in terms of both uncarbonized achene length and uncarbonized size index (ESM 12, 13). Similarly, the Newt Kash Hollow kernel, measuring 7.0×2.9 mm, is much larger than the DeSoto population uncarbonized kernels both in terms of length and size index (ESM 14, 15). There are a number of sites in the eastern Ozarks in addition to Newt Kash Hollow that could very well have sunflower specimens that predate 3000 B.P., pending direct AMS age determination (see Yarnell 1978; Gremillion 1994; Bonzani et al. 2007).

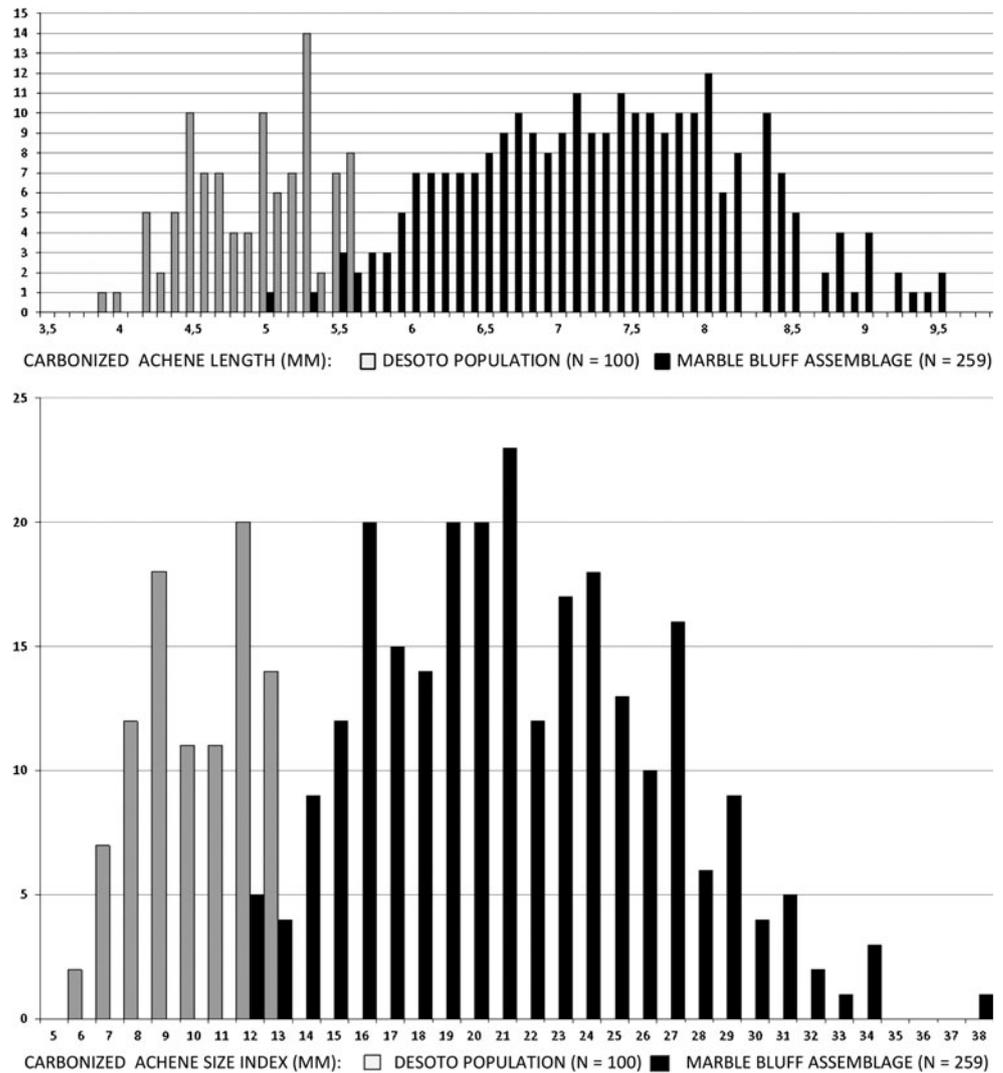
Riverton

Recent reanalysis of the crop plants from the Riverton site in Illinois (Smith and Yarnell 2009) included obtaining AMS radiocarbon dates on nut fragments from four features, one of which (Feature 8A) yielded a carbonized sunflower kernel (Fig. 8). Ranging in age from 3620 to 3800 B.P., the four Riverton dates indicated a short time span of site occupation and provided a secure date for the sunflower kernel as well as the other crop plants found at the site. Measuring 5.2×3.0 mm, the sunflower kernel falls well outside the DeSoto carbonized kernel size range both in terms of kernel length and kernel size index (Figs. 9a, b).

Napoleon Hollow

First described more than 25 years ago (Asch and Asch 1985), and recently reanalyzed and documented in detail,

Fig. 7 Marble Bluff *Helianthus* achenes compared to the modern wild DeSoto *Helianthus* population: **a** achene length; **b** size index values ($L \times W$)



the *Helianthus* assemblage from the Napoleon Hollow site in west-central Illinois consists of seven carbonized kernels or kernel fragments, one of which has an adherent fragment of shell or pericarp (Asch and Asch Sidell 2012). Four of the seven carbonized kernel specimens were recovered from a shallow Titterington phase pit feature (Feature 20) that also contained abundant artefacts and plant remains, including *Cucurbita* rind fragments, *Chenopodium berlandieri* and *Ambrosia trifida* seeds, along with 44 carbonized *Iva annua* achenes (Fig. 1, Table 1). Based on their large size and a direct date of 4400 cal. years B.P., this substantial assemblage of *I. annua* achenes provides the earliest evidence for the domestication of this species (Asch and Asch 1985, p. 161; Smith 2006a, 2011; Wiant et al. 2009).

It has been suggested that the *Iva*, *Helianthus*, *Chenopodium*, *A. trifida*, and *Cucurbita* specimens present in Feature 20 at the Napoleon Hollow site may represent a Titterington phase Archaic horticultural complex similar to that documented for the Riverton site 600 years later

(Asch and Asch 1985), and two of the four *Helianthus* specimens from this shallow pit provide additional support for this idea. The one intact carbonized kernel (F20-1 bot 1, 5.01 × 1.72 mm, Table 1) (Fig. 10a) is considerably larger than the DeSoto reference class in terms of length (Fig. 9a), and also falls just outside the upper end of the DeSoto reference class in terms of size index (Fig. 9b). In addition, a second kernel (F20-01 bot 2, >4.23 × ~1.5 mm, Table 1) (ESM 16), falls at the upper edge of the DeSoto reference class in terms of both length and size index, even though its tip is missing (Figs. 9a, b). The other two *Helianthus* specimens from Feature 20 (F20-1 bots 3 and 4) are too fragmentary to yield useable length or width measurements (Table 1).

In addition to the four kernels recovered from Feature 20 at the Napoleon Hollow site, three were recovered from midden contexts between the Titterington phase horizon and an underlying Helton phase horizon, and pending direct AMS dating, they have been assigned an age range

Table 1 Sunflower achenes and kernels recovered from sites that predate 3000 B.P.

Site	Age		Achene/Kernel			Specimen type, radiocarbon lab number, catalogue number, reference
	cal. years B.P.	¹⁴ C years B.P.	L	W	L × W	
Marble Bluff	3050	2926 ± 40	Fig. 7a	ESM 11	Fig. 7b	Carbonized achenes, SMU 1682, AK 34-23-327, (Fritz 1997)
Newt Kash	3300	3060 ± 40	9.3	3.7	34.4	Uncarbonized achene
Riverton	3800	3440 ± 40	7	2.9	20.3	Uncarbonized kernel, β215857, UMMA 16389
Napoleon Hollow	4400	3920 ± 40	5.2	3	15.6	Carbonized kernel, β253117, NMNH, (Smith and Yarnell 2009);
			5.01	1.72	8.61	Carbonized kernel, F20–01 bot 1
			>3.76	>1.34	>5.03	Carbonized kernel fragment, F20–1 bot 3
			≥2.93	>1.35	≥3.95	Carbonized kernel fragment, F20–1 bot 4
			>4.23	~1.70	~7.19	Carbonized kernel/achene fragment, F20–01 bot 2, β 216463, (Asch and Asch 1985; Asch and Asch Sidell 2012; Wiant et al. 2009)
Hayes	4840	4265 ± 65	4.4	1.5	6.6	Carbonized kernels, β45050, ETH8075
			5.6	2.3	12.9	
			5.15	2	10.3	
			5.3	2	10.6	
			5.6	2	11.2	
			5.7	2.6	14.8	
			5.3	2.1	11.1	(mean for six kernels) (Crites 1993)
Napoleon Hollow	5800–4400	5050–3900	4.65	1.79	8.32	Carbonized kernel, Sq 3–11, S 1/2
			≥1.84	2.09	>3.84	Carbonized kernel fragment, Sq 3–11, S1/2, (Asch and Asch Sidell 2012)
Napoleon Hollow	5800?	5050?	>3.93	2.14	>8.41	Carbonized kernel, Sq 80–15 (Asch and Asch Sidell 2012)
Koster Horizon 6	5990–5800	5250–5050	4.62	1.57	7.25	Carbonized kernel, Horizon 6, F1595, (Asch and Asch 1985; Asch and Asch Sidell 2012, Wiant et al. 2009)
Koster Horizon 6	6500–6000	5700–5300	~4.14	1.93	8	Carbonized achene, Horizon 6, F1542, (Asch and Asch Sidell 2012)
Koster Horizon 9A	8500	7800 ± 160	3.44	1.58	5.43	Carbonized achene, Horizon 9A Sq 224–031, ISGS-316, (Asch and Asch 1985; Asch and Asch Sidell 2012)

of 5800–4400 B.P. (5050–3900 uncal B.P.) (Table 1, Asch and Asch Sidell 2012). While one kernel (Sq 3–11 S 1/2 bot 2) is too fragmentary to provide useable length or size index measurements, a second is intact (Sq 3–11 S 1/2 bot 1, 4.65 × 1.79 mm) (Fig. 10b), and the third is missing only a small portion of its tip (Sq 80–15 bot 1, >3.93 × 2.14 mm) (Fig. 10c). The intact kernel falls above the DeSoto size range for both length and size index, while the almost intact kernel falls within the DeSoto wild baseline size range for length, but above it for size index (Figs. 9a, b).

Hayes

Analysis of a flotation sample recovered from a depth of 130–140 cm below the ground surface in a small block excavation unit at the Hayes site in central Tennessee

yielded six complete carbonized sunflower kernels (Crites 1987), one of which was directly dated to 4840 cal. B.P. (Crites 1993) (Figs. 1, 10d, Table 1). Measuring from 4.4 to 5.7 mm in length, all of the Hayes site *Helianthus* specimens are larger than the DeSoto wild baseline population in terms of kernel length (Fig. 9a), and all but one have size index values larger than the DeSoto *Helianthus* (Fig. 9b). Unfortunately, the *Helianthus* specimens from Hayes, which represent the earliest record of this domesticated crop plant, are no longer present in the archaeological collections of the University of Tennessee, and their current location is unknown.

Koster

Two carbonized *Helianthus* achenes and a single carbonized kernel were recovered from different contexts at the



Fig. 8 The carbonized *Helianthus* kernel from Feature 8A, Riverton Site (photograph by Scott Whitaker)

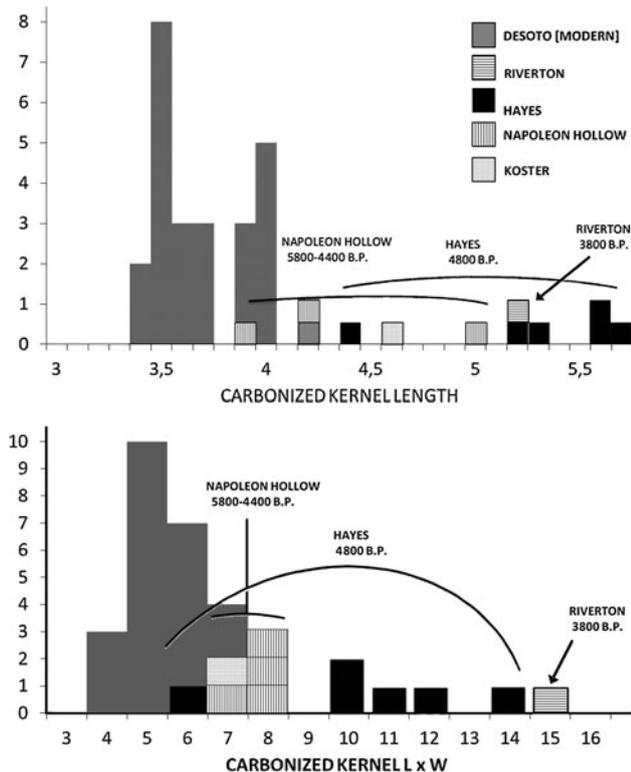


Fig. 9 Carbonized archaeological *Helianthus* achene and kernel specimens compared to the modern wild DeSoto collection

Koster site in west-central Illinois (Fig. 1, Table 1). Pending direct AMS dating, the kernel, recovered from Horizon 6 Feature 1595C, has been assigned an age range of 5900–5800 B.P., while the two achenes have been estimated to date to 6500–6000 B.P. (Horizon 6, Feature 1542), and 8500 B.P. (Horizon 9A-Sq 224–031) (Table 1, Asch and Asch Sidell 2012). Both of the achenes fall toward the lower end of the DeSoto wild reference class histograms in terms of both length and size index (ESM 17–20). The single kernel recovered from Koster (4.62×1.57 mm) falls above the DeSoto population size range in terms of length, but within the DeSoto size index histogram (Figs. 9a, b, and 10e).

Discussion

Widely scattered in space and time, the *Helianthus* assemblages recovered from the six sites described above highlight both the substantial gaps in our current understanding of *Helianthus* domestication, and how future research can begin to fill in what is now only the barest of outlines of the early history of this important crop plant. Looking for evidence of *Helianthus* domestication in the archaeological record is basically a straightforward process of identifying and documenting ancient specimens of *H. annuus* that exhibit morphological characteristics that are not present in wild populations of the species, and which can be attributed to the changing selective pressures associated with the adaptive syndrome of domestication such as an increase in seed size. Charles Heiser began looking for evidence of *Helianthus* domestication in the 1940s, and his remarkable series of subsequent studies, as detailed above, have shaped research on the question for more than six decades.

Heiser's continent-scale collection of *H. annuus* populations and his comprehensive documentation of within and between population variations in *Helianthus* morphology have provided the general profile employed in defining what wild *Helianthus* disks, achenes and kernels look like. Heiser also acknowledged and addressed the problems associated both with introgression between wild and domesticated *Helianthus* populations and with the shrinkage of archaeological specimens due to carbonization. Having established a morphological profile for modern wild sunflower, Heiser then looked at archaeological collections in a number of different museums and other repositories, and provided a clear research protocol for identifying ancient specimens of domesticated *H. annuus*.

In this article I have retraced the general research pathway first charted by Heiser. Advances in genetics now allow for better control over the complications associated with introgression between domesticated and wild



Fig. 10 Carbonized *Helianthus* kernels from the Napoleon Hollow site: **a** Feature 20–1 bot 1 (5.01 × 1.72 mm); **b** Square 3–11 s ½ bot 1 (4.65 × 1.79 mm); **c** Square 80–15 bot 1 (>3.93 × 2.14 mm). **d** from the Hayes site (5.3 × 2.1 mm); **e** from the Koster site Horizon

6 (Feature 1595, 4.62 × 1.57 mm). Photos **a–c**, **e** courtesy of David Asch and Nancy Asch Sidell (Asch and Asch Sidell (2012)); **d** courtesy of Gary Crites

Helianthus populations, and by replacing Heiser's regional composite profile with one based on a single modern population that is both genetically close to sunflower's wild progenitor and which exhibits little evidence of introgression with domesticated plants (the DeSoto population), it was possible to define a more accurate wild baseline of comparison that can be used in the identification of domesticated *Helianthus* specimens in the archaeological record.

The DeSoto population also allowed for an alternative approach to addressing the problem of shrinkage of archaeological specimens due to carbonization. Rather than having to employ various correction multipliers in order to estimate the original, pre-shrinkage size of ancient carbonized achenes and kernels, carbonization of DeSoto specimens instead enabled the development of wild baseline profiles for carbonized achenes and kernels that can be directly compared to ancient carbonized specimens. When combined with the DeSoto-derived uncarbonized achene and kernel profiles, these carbonized profiles can be used to consider the wild versus domesticated status of archaeological specimens without having to rely upon carbonization correction estimates. In addition, the DeSoto population and other stands similarly identified as genetically close to the wild ancestors of *H. annuus* hold the potential of providing additional material for further study of shrinkage in sunflower achenes and kernels due to carbonization, and can facilitate attempts to replicate the results reported here.

I began consideration of the archaeological remains relating to *Helianthus* domestication with an expanded analysis of the large and well-dated assemblage of carbonized sunflower achenes recovered from the Marble Bluff site in Arkansas, previously documented by Fritz (1986, 1994, 1997). Dating to 3000 years B.P., the Marble

Bluff assemblage of 259 achenes falls almost completely outside of the size range distribution of the DeSoto wild baseline population, providing both compelling evidence for the presence of a domesticate and a solid starting point for looking back in time for earlier potential evidence of the temporal and spatial context of *Helianthus* domestication.

One of the most obvious points to be made regarding the archaeological record for *Helianthus* in eastern North America prior to 3000 B.P. is the small number of early specimens, either wild or domesticated, that have so far been identified as predating Marble Bluff, with a total of only 19 achenes and kernels being reported from five sites (Table 1). This relative scarcity underscores the importance of careful curation and detailed documentation of the early assemblages identified to date, as well as the strong possibility that additional *Helianthus* achenes and kernels predating 3000 B.P. are currently curated in museum collections and remain to be identified, dated, and documented. Even poorly provenanced solitary specimens such as the Newt Kash Shelter achene (Fig. 2) can provide important new evidence regarding the early history of domesticated *Helianthus*.

Scattered along a rough east to west transect between 35° and 40° North latitude that stretches from eastern Kentucky (Newt Kash) through Tennessee (Hayes) and Illinois (Riverton, Napoleon Hollow, Koster) to northwestern Arkansas (Marble Bluff) and extending across a considerable span of time, the six *Helianthus* assemblages that have been clearly shown to predate 3000 B.P. provide only the barest outline of the early history of this important crop plant.

At the early end of this developmental sequence, the two achenes recovered from Horizon 6 and Horizon 9A contexts at the Koster site in west-central Illinois fall

comfortably within the DeSoto population size range, indicating the presence and human utilization of wild stands of *Helianthus* toward the western margin of the eastern woodlands beginning as early as 8500 B.P. Given the absence of other *Helianthus* specimens from sites outside of west-central Illinois between 8000 and 5000 B.P., However, it is not possible to either establish the likely spatial extent of wild populations of this species in eastern North America over this three-millennia span, or to track any temporal shifts in its geographical range that may have occurred in association with the dramatic climatic changes that occurred during the Middle Holocene (Brown 1985; Smith 1986).

Closing out the early chapters of *Helianthus* domestication, the large assemblage of achenes recovered from Marble Bluff provides clear evidence of the presence of a domesticated crop plant, and after 3000 B.P. the number of sites across eastern North America yielding domesticated *Helianthus* specimens steadily increases (Yarnell 1978, 1981).

Between the achene assemblages of Koster (wild) and Marble Bluff (convincingly domesticated), over a span of perhaps 3,000 years (6000–3000 B.P.), the archaeological record of sunflower in eastern North America consists of only 15 specimens from four sites (Table 1). The single specimens from the Newt Kash shelter (3300 B.P.) and the Riverton site (3800 B.P.), along with five of the six kernels recovered from the Hayes site (4800 B.P.), are all directly dated, and all fall well above the DeSoto wild reference class in terms of both length and size index measurements (Figs. 9a, b), providing three isolated data points across a vast spatial and temporal expanse. At present, the assemblage of carbonized kernels from the Hayes site provides the earliest directly dated report of domesticated sunflower in eastern North America. It is unfortunate that they are not at present available for additional dating and documentation.

The *Helianthus* assemblages from the Koster and Napoleon Hollow sites, however, offer several possible indications that the initial domestication of *Helianthus* may have in fact occurred not in Tennessee, but farther west in the Oak Savannah Forest region that is closer to the present day center of distribution of wild progenitor *H. annuus* populations, and which has also produced the earliest evidence for the domestication of the other three indigenous domesticates of eastern North America: *C. pepo* at Phillips Spring, *I. annua* at Napoleon Hollow, and two varieties of *Ch. berlandieri* at Riverton (Fig. 1). While five of the ten kernels recovered from the Napoleon Hollow and Koster sites are either too fragmentary to provide length and width measurements, or fall with the size range of the DeSoto wild population reference class, the remaining five kernels stand out as possibly reflecting a size increase associated with domestication. Of the four kernels

recovered from the Titterington phase Feature 20 at the Napoleon Hollow site, one falls above the DeSoto population size range in terms of both length and size index, while a second falls at the upper end of the DeSoto histograms for both length and size index, even though it is missing its tip. While these specimens date approximately four centuries after the much larger Hayes site kernels, two other kernels from Napoleon Hollow, and one from Koster, may be older than the Hayes site specimens. Two kernels estimated to date between 5,800 and 4,400 B.P. both fall just above the DeSoto size range in terms of size index, and one of them is also above the size range of the DeSoto population in terms of length (Table 1, Figs. 9a, b). Similarly, the kernel recovered from Horizon 6 at the Koster site that is estimated to be 5,990–5,800 years old is larger in terms of length than the DeSoto reference class and falls at the upper end of the DeSoto size index histogram.

Several factors, however, will complicate any effort to build an argument in support of the three Koster Horizon 6 and Napoleon Hollow kernels representing domesticated plants. Direct AMS dates would first have to be obtained on the specimens to show that they predate the Hayes site assemblage. Secondly, while the DeSoto population offers a more appropriate and robust wild reference class for the assessment of wild versus domesticated status of archaeological specimens than the modern comparative collections previously employed, it could be argued that given the general west-to-east clinal increase in the size of *Helianthus* achenes, and the location of the Koster and Napoleon Hollow sites 400 miles to the east of the DeSoto National Wildlife Refuge, wild sunflower populations in west-central Illinois more than 5,000 years ago may have produced larger achenes than those collected for this study from a modern population in western Iowa. It should be noted, however, that the carbonized achenes from Horizons 6 and 9A at the Koster site do fall into the wild DeSoto size range (ESM 17, 18). In addition, as shown in ESM 5, there is a sufficient range of variation in the shrinkage rate of sunflower achenes and kernels during carbonization to suggest caution in interpretation of any archaeological specimens that fall outside of, but close to, the upper end of wild population size measurements. Carbonized achenes and kernels that are considerably larger than those in a modern wild reference class (with this size differential often expressed as a percentage—e.g. 25 % greater length) obviously constitute stronger evidence of domestication and appropriately conservative and substantially buffered standards for assigning domesticated status to archaeological specimens have long been employed. Finally, the three kernels recovered from different cultural contexts at Koster and Napoleon Hollow represent a relatively small sample on which to build a case for domestication.

Further consideration of the possibility that the initial domestication of the *Helianthus* may have occurred in the Oak-Savannah Forest region, in closer cultural and environmental association with the domestication of the other three eastern domesticates, will clearly rest on a broad regional-scale search for, and documentation of, additional early sunflower assemblages throughout the mid-latitudes of eastern North America. Important new evidence for the early history of this important crop plant will come both through the analysis of newly excavated material, and the expanded consideration of extant museum collections.

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