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A New Record of Domesticated Little Barley (*Hordeum pusillum* Nutt.) in Colorado: Travel, Trade, or Independent Domestication

ANNA F. GRAHAM¹, KAREN R. ADAMS², SUSAN J. SMITH³,
AND TERENCE M. MURPHY⁴

¹ Department of Anthropology and Research Laboratories of Archaeology, University of North Carolina at Chapel Hill, CB # 3115, Chapel Hill, NC 27599, USA, annafig@live.unc.edu; annafullergraham711@gmail.com

² Archaeobotanical Consultant, 2837 E. Beverly Dr., Tucson, AZ 85716, USA

³ Consulting Archaeopalynologist, 8875 Carefree Ave., Flagstaff, AZ 86004, USA

⁴ Department of Plant Biology, University of California, Davis, CA 95616, USA

Little Barley Grass (*Hordeum pusillum* Nutt.) is a well-known native food domesticated in the U.S. Southwest by prehistoric Hohokam farmers in Central and Southern Arizona. This domesticated grass has recently been recovered from a late Basketmaker III community in southwestern Colorado, far from its well-known Hohokam region. Although travel or trade could explain this new Colorado record, we review morphological, ecological, and other types of evidence to consider a case for independent domestication. This case is supported by Old World molecular evidence for independent domestications of wild barley (*Hordeum spontaneum*) in both the Near East and Tibet. Simple mutations, frequent in nature, can produce wild plant populations of possible interest to humans. Supporting evidence exists in the form of larger than usual grass pollen grains. Supplemental plausibility arguments can include prior familiarity with the domestication process, and finding modern mutations such as free-threshing grains or larger-than-normal polyploid plants. Molecular assessments of modern populations can elucidate Little Barley relationships between major regions of North America, subregions of the U.S. Southwest, and uncharred archaeological specimens. This new Little Barley example presents evidence upon which such stories are

crafted, and reveals the importance of native domesticates in ancient subsistence regimes.

El pasto de cebada pequeña (*Hordeum pusillum* Nutt.) es conocido como un alimento nativo del Sudoeste de los Estados Unidos que fue domesticado por los agricultores prehispánicos del centro y sur de Arizona. El pasto de cebada pequeña domesticado fue recuperado en una comunidad del periodo tardío 'Basketmaker III' en el Suroeste de Colorado, lejos de la región Hohokam de Arizona donde comúnmente se conocía. El comercio o los viajes podrían explicar este registro en Colorado, sin embargo, se revisó la evidencia morfológica y ecológica, entre otras, para evaluar una posible domesticación independiente en esta región. Este estudio de caso se sustenta por evidencia molecular de domesticación independiente de cebada silvestre (*Hordeum spontaneum*) en el Viejo Mundo, tanto en el Cercano Oriente como en el Tíbet. Las mutaciones simples, frecuentes en la naturaleza, pueden producir poblaciones silvestres de plantas con posible interés para los humanos. Los grupos humanos que han domesticado otros recursos silvestres como el agave, estarían ya familiarizados con el proceso de domesticación. Otra evidencia existente pueden ser los granos de polen de pasto más grandes que lo normal. Además, otros argumentos complementarios incluyen la búsqueda de plantas modernas para identificar la presencia de mutaciones tales como los granos de trillado libre o las plantas poliploides de mayor tamaño que lo normal. La evaluación molecular de las poblaciones modernas pueden elucidar las relaciones de la cebada pequeña entre regiones principales de norte América y entre subregiones del Sudoeste de Estados Unidos, además que se pueden comparar con los especímenes arqueológicos sin carbonizar. Este ejemplo de la cebada pequeña del sudoeste de Colorado es un recordatorio del importante papel que jugaron las domesticaciones nativas en los regímenes de subsistencia de los antiguos pobladores y presenta el tipo de evidencia de la cual dichas historias son creadas.

KEYWORDS Little Barley, Domestication, Basketmaker III

The importance of three Mesoamerican crops in prehistoric subsistence strategies is well known for the Southwest U.S. states of Arizona, New Mexico, Colorado, and Utah. Current information suggests that maize (*Zea mays*), beans (*Phaseolus* spp.), and squash (*Cucurbita* spp.) were initially traded up from the south over a 2,000-year period between 4,200 and 2,600 years ago (Merrill et al. 2009). Mesoamerican domesticates offered resource security and the possibility for surplus production, which then encouraged larger populations, the formation of sedentary communities, and the evolution of complex societies.

The management and domestication of indigenous wild plants offer less well known but fascinating stories of their own. Agave (*Agave*), cholla (*Opuntia*),

and Little Barley (*Hordeum pusillum* Nutt.), are three examples of indigenous plants with evidence of cultivation, management, and/or domestication in prehistory (Bohrer 1991). Agave and cholla have both been cited as managed plants based on pollen and macrobotanical remains occurring outside the natural range for those plants (Fish 1984; Miksicek 1984). Little Barley, an annual grass, identified as domesticated on the basis of morphological changes, has been previously recovered at numerous sites throughout central and southern Arizona spanning from 2410 ± 40 BP to AD 1450 (Adams 2014:159). Use of barley grains approximately 1,500 years earlier has also been reported from McEuen cave in southeastern Arizona (Lisa Huckell, personal communication 2017; Shackley 2005).

Recently discovered evidence for domesticated Little Barley (*Hordeum pusillum* Nutt.) in southwestern Colorado during the Basketmaker III period (AD 500–700) provides further emphasis on the role of domesticated indigenous crops in the subsistence practices of Southwest U.S. prehistoric communities. Equally interesting is the issue of whether this happened independently of Little Barley domestication in central and southern Arizona or elsewhere in North America. A number of domesticated plants of the prehistoric era that were extinct by historic times could reasonably be considered for redomestication today (Minnis 2014).

In this paper, barley is used as an example for presenting how domestication is determined. That discussion is followed by the introduction of a new record. The new find from Southwest Colorado both presents new data and demonstrates how domestication arguments can be constructed.

Modern Barley Distributions

Wild *Hordeum pusillum* Nutt. populations have broad ecological amplitude in North America, today growing in nearly all of the United States and in the western Canadian provinces (USDA PLANTS 2016). It presently grows in some, but not all, portions of the Four-Corners states of Arizona, New Mexico, Colorado, and Utah, and presumably did so in prehistory as well. Though wild Little Barley is said to be “widely distributed in Colorado” (Harrington 1964:72) and has been documented by others in adjacent northeastern Arizona and southeastern Utah (USDA PLANTS 2016), the authors have not directly observed it in southwestern Colorado (Montezuma County), perhaps because it has been out-competed historically by aggressive Old World wild barley species.

Old World barley species introduced to the Americas following the arrival of Columbus include wild *Hordeum marinum*, *Hordeum murinum*, and domesticated *Hordeum vulgare* (USDA PLANTS 2016). Of these three species, *Hordeum murinum* is commonly widespread at present. As an aggressive weed, *Hordeum murinum* appears to have completely taken over native Little Barley’s former niche in some locations. *Hordeum murinum* plants are noticeably different from *Hordeum pusillum* when the two are compared side by side. Though their grains (in the grass family, a “grain” is a fruit technically referred to as a caropsis),

have similar morphological features, such as size of the embryo depression and a lengthwise shallow groove down the ventral face, non-native *Hordeum murinum* grains are much larger than those of native *Hordeum pusillum* (Figure 1). Exactly when *Hordeum murinum* was introduced from Eurasia into North America is not entirely clear. It is mentioned as introduced in a USDA bulletin from 1897, indicating that, if not widespread, the grass was notably present within the United States at that time (Lamson-Scribner and Smith 1897). Today it is widespread in the Cortez, Colorado area.

Criteria of Plant Domestication

One key issue in building a case of domestication is the evidence relevant to recognizing a wild from a domesticated form. Different types of evidence utilized for other plants include: morphological change(s), ecological evidence, and so-called “plausibility arguments.”

Morphological change is one of the more common types of evidence used to demonstrate a plant’s transition to domestication. Depending on the plant species, morphological change is manifested in a variety of ways. Some species, such as marsh-elder/sumpweed (*Iva annua*), sunflower (*Helianthus annuus*), and erect knotweed (*Polygonum erectum*) have larger achenes (fruits) in their domesticated varieties (Asch and Hart 2004; Smith 1992b), resulting in higher food yield. Other species, such as goosefoot (*Chenopodium berlandieri*) and pigweed (*Amaranthus*



FIGURE 1. Modern, wild *Hordeum pusillum* (left) grains are much smaller in size than those of invasive, Old World *Hordeum murinum* (right). Left ventral views of each grain pair reveal a long shallow groove down the center; right dorsal views of each grain pair have a small embryo depression visible at base. Note that the papery palea and lemma are firmly attached to all grains.

spp.) developed a thinner seed coat, or testa, during domestication (Asch and Hart 2004; Fritz et al. 2009). The source of morphological changes can be genetic mutations or natural/cultural selection pressures on a plant species.

Ecological evidence can also demonstrate cultivation and subsequent domestication of a plant by human groups. Evidence of a plant growing outside of its known or inferred species range (natural growing area) has been used as evidence of cultivation by ancient groups (Bohrer 1991; Hodgson 2006). For example, few wild stands of agave currently grow at the same lower elevations as the archaeological sites yielding these specimens, and their occasional abundance demonstrates human efforts that have altered their natural distribution and abundance (Fish et al. 1985). Bohrer (1991) also acknowledges the possibility of long distance trading or transport as well as the idea that these examples may represent local cultivars (cultivated varieties). Abundance and broad distribution of remains within an archaeological site can be used as a line of reasoning supporting local cultivation rather than transportation of plants from elsewhere (Bohrer 1991).

Plausibility arguments might deal with a variety of societal or cultural factors that can point toward or suggest domestication of a particular species. These factors include: “economic importance; lack of barriers to artificial propagation; the cultivation of similar species elsewhere; ethnohistoric evidence of cultivation; a documented temporal increase in abundance prehistorically; and an increase in human population levels and sociopolitical complexity, implying an agricultural base” (Smith 1992b:108). Other plausibility arguments discussed below could include: the tendency of a species to repeatedly produce recognizable mutations; possibilities of polyploidy; recovery of larger than usual pollen grains; prior familiarity with the process of domesticating wild plants; and various types of molecular evidence.

Old World Barley, *Hordeum vulgare*

Precedent for domestication of a wild barley species exists in the Old World. There, a domesticated barley (*Hordeum vulgare*), commonly known as “pearl barley” and used in soups and other dishes, ranks as the fourth cereal produced in the world today (Tanno 2014). *Hordeum vulgare* was domesticated from wild *Hordeum spontaneum* in the Old World very early on (Zohary et al. 2012). Morphological changes indicating domestication are dated to 6000 BC in Anatolia (Harlan 1979). Molecular evidence has demonstrated that barley was also independently domesticated from wild populations growing on the high, cold Tibetan Plateau (Dai et al. 2012:169–179).

Accounts of Columbus’ early voyages to the Americas detail barley as one of the crops brought from the Old World (Dunmire 2004). A little more than a hundred years later, this Old World barley reached the Southwestern U.S. via the Spanish. Documents show that Old World barley was introduced to New Mexico between 1598 and 1630 AD (Dunmire 2004:176). The earliest citation for Old World Barley in Arizona is 1701 AD, based on evidence embedded in adobe bricks at the Mission in Tumacacori, Arizona (Hendry 1931). Likewise, Spanish accounts demonstrate the introduction and subsequent usage of Old World Barley in California sometime before 1795 AD (Dunmire 2004:299).

Old World Evidence: Morphological Changes

Researchers in the Old World have long recognized certain morphological changes as indicators of the domestication of *Hordeum vulgare* from wild *Hordeum spontaneum* populations. Four Old World morphological traits pertinent to a discussion of domestication are reviewed here (Table 1). A range of additional traits associated with domestication, such as synchronous tillering, uniform maturation, rapid germination, and seedling vigor, are discussed in more detail in the publications cited in Table 1.

Hull-less Grains. One prominent trait indicative of Old World barley domestication was the development of hull-less (naked) grains, reported to be the result of a single mutation (Table 1). Protective paleas and lemmas (surrounding chaffy parts) no longer adhered tightly to the grains, resulting in free-threshing grains that made harvesting and post-harvest processing easier. Ventral grain surfaces of hull-less grains can appear transversely wrinkled or rippled, and have no evidence of adhering chaffy protective parts.

Six-Row Form. Reactivation of fertility in sterile florets is another trait recognized in the Old World barley archaeological record. A floret is a special term for a grass flower that produces a grain (caryopsis) and protective paleas and lemmas. During domestication, sterile, reduced, or suppressed lateral florets became fertile grain-producing florets, apparently also via a single mutation (Harlan 1975; Helbaek 1966). The plant essentially went from a two-rowed wild form to a six-rowed domesticated form. Evidence for this was expressed in grain shape: two lateral (formerly sterile) florets produced asymmetrical grains for every single central (fertile) symmetrical floret, in the ratio of 2:1. Such a mutation resulted in significantly increased grain yields.

Increase in Grain Size. Another indicator of Old World barley domestication was an increase in grain size (Harlan 1975). Increase in grain size occurs when seedlings are forced to compete for space and nutrients, especially when planted or broadcast by humans to produce a future crop. Basically, the amount of endosperm (food for the embryo) increases, as seedlings need more internal food reserves to develop quickly under the competitive conditions of dense spacing within an agricultural field. In the Old World, grain width became greater than 50% of grain length. Larger grains generally represent an increase in the amount of carbohydrates within each grain (Harlan 1975:131). The result for humans was higher caloric returns.

Non-shattering rachis. Finally, a tendency to go from a shattering to a non-shattering rachis (flowering stem) was evident when sections of the rachis began adhering to each other, allowing easier collection of grains. This trait ensured less grain loss during harvest. Once again, the result led to higher grain yields for the harvesters.

New World Barley, *Hordeum pusillum* Nutt.

Evidence utilized to distinguish wild from domesticated barley in the Old World has been used in the New World as well. The assumption is that New World human

TABLE 1
SELECT MORPHOLOGICAL TRAITS UTILIZED IN THE OLD WORLD FERTILE CRESCENT REGION THAT SINGALED DOMESTICATION OF WILD *HORDEUM SPONTANEUM*

Parts	Caryopsis (grain) condition	Caryopsis size	Planting unit	Rachis (stem)
Trait change	Hull-less (naked) grains	Larger grains, wider grains	From one fertile (central) and two sterile (lateral) florets to three fertile florets	From shattering to non-shattering
Evidence	Palea and lemma not cemented to grain; ventral grain surfaces can appear transversely wrinkled or rippled	Increase in grain size through time	Grain shape affected; now get two twisted lateral grains for every non-twisted central grain	Sections of rachis remain attached to each other
Explanation	Single mutation, favored by humans	Over time, seedlings planted by humans compete better when they have more reserves to draw upon	Single mutation, favored by humans	Over time, harvest by humans favors non-shattering parts
Implications	Free-threshing; post-harvest processing easier	Grains produce increased carbohydrates	Grain yield per plant is increased substantially	Less grain loss during harvest
References	Harlan (1975:129–130); Harlan (1979:27); Helbaek (1966:355–359); Stubbe (1959)	Harlan (1975:131)	Harlan (1975:129–130); Helbaek (1966)	Harlan (1975:129–130)

selection pressures on a wild *Hordeum* species might result in some or all of the same morphological changes seen in the Old World. Broadly distributed plants with similar genetic and phenotypic traits, in this case different populations or species of wild barley on different continents, may react in similar ways under human selection pressures. Based on this assumption, there is now widespread evidence that an independent domestication of a New World species of barley, *Hordeum pusillum*, occurred thousands of years before initial European contact. This domesticate has been reported in major regions of the United States including the Southwestern U.S., the Southeastern/Midwestern U.S., and in California.

Southwestern U.S.: Central and Southern Arizona Hohokam

The story of domesticated Little Barley use in the Southwestern U. S. prehistoric era has been summarized by Adams (2014) in a synthesis that presents a comprehensive review of *Hordeum pusillum*. Sites preserving evidence of domesticated Little Barley range from those in the Northern Hohokam periphery north of Phoenix, to those in the Phoenix Basin, the Middle Gila River Valley, and the Tucson Basin (Adams 2014). Previous inquiries to numerous archaeobotanical colleagues yielded no additional records of domesticated *Hordeum pusillum* grains outside of central and southern Arizona. However, grass grains in Southwestern U.S. archaeological sites are often identified only to the family (Poaceae) level; further work is needed to build a comparative grass database by systematically measuring and describing the grains of wild grasses (see Adams 2001:69–70) to assist in easier identification. This effort should include grasses known ethnographically (Doebley 1984) and/or archaeologically to have been of importance to human groups.

In the Southwestern U.S., Little Barley grass was gathered over a broad time range from the Early Agricultural Period into the Hohokam Classic period. In southern and southeastern Arizona, the Early Agricultural period includes the San Pedro Phase (1200–800 BC), followed by the Early Cienega (800–400 BC) and Late Cienega (400 BC to AD 500) phases (Mabry 2008:73, Table 3.8). A seasonal campsite in the Tucson Basin, considered to date between ca. 1200 and 600 BC, preserved charred Little Barley grass grains (Miksicek 1989) in the San Pedro phase. Another charred domesticated Little Barley grain from a context in a Northern Periphery Sunflower Valley site (Adams 2003:226), radiocarbon dated to ca. 2410 ± 40 BP, securely confirms *Hordeum pusillum* cultivation in the Early Agricultural period there as well. Two charred *Hordeum* caryopses (grains), identified by Lisa W. Huckell, have been reported from McEuen Rockshelter (AZ W:13:6 (ASM)) in the Gila Mountains of southeastern Arizona (Shackley 2005). These specimens date to 3887–4145 BP and 2347–2705 BP (dates with multiple intercepts), extending the known record of barley use back another nearly 1,500 years. Huckell has described the more than 340 McEuen cave specimens as “... present in most flotation samples ... preservation is really good ... almost all with intact surfaces are smooth ...” (Lisa Huckell, personal communication 2017).

The level of use of domesticated Little Barley in central and southern Arizona fluctuated through time. Use peaked in the pre-Classic period (AD 700–1150), and declined through the Classic period (AD 1150–1450). No evidence has been

found in the Southwest U.S. for continued use of domesticated Little Barley into the historic period (Doebley 1984). This is one of many examples of a domesticated plant that faded from human subsistence practices prior to the historic era (Minnis 2014).

In the Southwestern U.S. the evidence for Little Barley domestication has rested entirely on morphological change, which can be best understood following a description of the plant and its parts. The flowering portion, or inflorescence, of a Little Barley plant ranges from 4 to 8 cm long and consists of alternating “planting units” comprised of three spikelets each (Figure 2). In the grass family, a spikelet

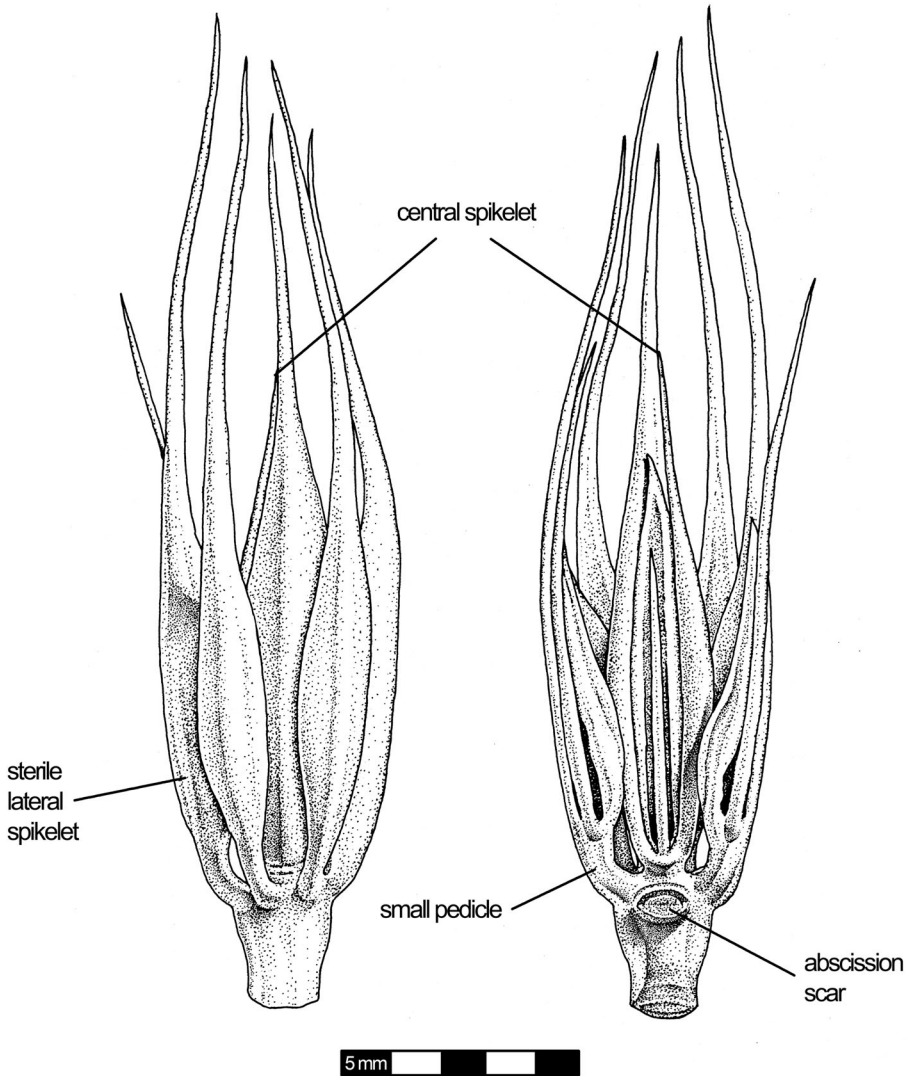


FIGURE 2. Drawing of *Hordeum pusillum* planting unit depicting the position of the central fertile spikelet and the two lateral sterile spikelets. Reprinted from Adams (2014) with permission of John McCool.

consists of one to many flowers (florets) subtended by two bracts known as glumes (Gould 1951:341). As they ripen these planting units break away (abscise) from the flowering stem, from the apex downward (Adams 2014: Figure 5.2). Within three-spikelet planting units, only the central spikelet has a fertile floret (defined above) capable of producing mature grains; the two lateral spikelets contain sterile florets (Figure 2). Each planting unit has a sharp basal tip, which allows the entire unit to slip into a crack in the soil, essentially “self-planting” itself. Sometimes a planting unit would cling to a passing animal for transport to an open niche elsewhere.

Hull-less grains. The most obvious morphological change to Little Barley affected the grains (Adams 2014). Like domesticated Old World barley, domesticated Little Barley has grains that readily fall free from their protective bracts upon maturation. The result is a hull-less grain that shows no evidence of the palea or lemma. In contrast, wild *Hordeum pusillum* grains retain their paleas and lemmas (Figure 3) as protective coverings when the planting units are dispersed from the plant. Efforts by researchers to completely remove those bracts from wild grains by processing methods have generally failed. It has been experimentally demonstrated that no amount of processing via soaking, abrading, parching, or various combinations of these processing steps, completely removes these protective chaffy parts from the wild grains (Adams 2014). Therefore the free-threshing nature of the grains is a morphological change considered solid evidence for domesticated Little Barley.

Non-Shattering Rachis. Another morphological change concerns the rachis, which is the stem that holds the planting units of the plant together. In nature,



FIGURE 3. Modern, wild *Hordeum pusillum* grains (left) with palea and lemma fragments still attached are next to ancient, charred *Hordeum pusillum* grains from the Switchback Site (right) with no evidence of palea and lemma. Small size of the two ancient specimens from the Switchback Site in SW Colorado likely caused in part by shrinkage during charring.

these stem segments naturally shatter (fall apart) when the plant is mature, allowing for the gradual dispersal of the planting units. This trait is not ideal for human gathering purposes as it allows for the potential loss of grains and a reduced grain yield. A non-shattering rachis would be visible in the archaeological record via rough scars from forcing joined planting units apart (Adams 2014). Limited rachis fragments surviving within the Southwest U.S. offer this rare form of evidence (Adams 2014:151–152).

Grain Size. Grain size has not been regularly recorded on Southwestern U.S. Little Barley specimens. Limited charred grain size evidence from two sites in Arizona report: (a) a mean length of 2.550 mm and mean width of 1.395 mm ($N = 64$) at La Ciudad (Bohrer 1987:85), and (b) a mean length of 2.43 mm and mean width of 1.39 mm ($N = 6$) at N:16:46 at the Central Arizona Ecotone Project (Bohrer 1984). Ten uncharred archaeological grains from Tonto National Monument measure a mean length of 3.54 mm and a mean width of 1.66 mm (Adams 1987:223). The difference between the smaller charred archaeological grains and the larger uncharred ancient grains from Tonto National Monument may be due to some amount of shrinkage that occurs when specimens become charred. Controlled charring experiments on modern mature grains would produce information on the percentage of shrinkage under varying charring scenarios.

Southeastern and Midwestern U.S.

Little Barley also has a long history as an indigenous domesticated plant in the Southeastern and Midwestern U.S. regions (Asch and Hart 2004). Evidence for domesticated Little Barley first appears during the Archaic period in Illinois at the Gardens of Kampsville site (Asch and Asch 1985). Subsequent archaeological evidence demonstrates active use of domesticated Little Barley by 1000 BC, with increasingly widespread cultivation in the following Early and Middle Woodland periods, 550 BC.–AD 250 (Smith 1992a). From the Late Woodland, up until the late prehispanic Oneota period (AD 1400–1500), Little Barley was utilized to varying extents, from low-level to major staple, across sites in the Midwestern U.S. region (Simon and Parker 2006).

The Midwestern U.S. Little Barley story has been well summarized by Hunter (1992). Based on a large archaeological sample in the Middle Mississippi River Valley region, Hunter reported three morphological changes that indicate Little Barley domestication. She discussed cases of transverse wrinkling or rippling on the ventral surface, resulting from loss of adhesion between the lemma and palea and caryopsis, leading to a hull-less grain, and she reported a limited number of lateral florets that were “twisted”, implying a six-row form was present. Hunter also noted statistically significant changes over time to larger mean grain width and overall size (length x width) on charred grains, although not to the extent (50% or more) of the increases noted in the Old World; however, application of a “correction factor” to estimate original size of charred specimens is based on limited experimentation. Hunter documented these three changes between the Middle Archaic to the Late Woodland time periods. Using an evolutionary model of plant domestication developed by Rindos (1984), Hunter tracked the changing

relationships between human groups and Little Barley over time. She concluded that incidental Little Barley domestication (humans protecting wild plants and dispersing harvested seeds) occurred during the Middle and Late Archaic periods; specialized Little Barley domestication (humans affecting the evolution of the domesticate) existed during the Terminal Archaic through Early Woodland periods; incipient agricultural domestication (farmers now manipulating the environment) prevailed during the Middle and Late Woodland periods; and finally a sharp decline in Little Barley use occurred following the Late Woodland period.

California

On the basis of morphological changes, archaeobotanists have also reported the presence of domesticated Little Barley within California, spanning the Archaic, Upper Emergent/Protohistoric, Late Prehistoric/Historic, and into the Mission periods (Hammett 1991; Miksicek 1999; Reddy 2009, 2015; Wohlgenuth et al. 2015a, 2015b). Three traits are presented as evidence: a hull-less grain condition; larger grain size; and the possibility of a six-row variety.

The hull-less grain condition is well established in California. In a summary article, Miksicek (1999:7–9 and Table K.8) reports that “In over fifteen years of examining thousands of archaeological barley seeds from sites in Arizona and California, I have only seen one example of a native barley caryopsis (grain) with adhering glumes”. Technically, the palea and lemma would be the adhering parts.

California archaeobotanists also consider increasing grain size over time as an indicator of domestication. Miksicek (1999:8) reported that Little Barley grains ($N = 81$) at the Late Prehistoric/Early Historic site CA-YOL-182 in the Sacramento Valley of northern California were 15% longer, 8% wider, and 6% thicker than the grains ($N = 10$) from a much older 5000 BC site (CA-SDI-6010) in southern California. Further evidence is provided by both Wohlgenuth (2004) and Hammett (1991), who agree with Miksicek (1999:7) that larger grain size could be the result of cultivation efforts. Wohlgenuth found a 33.8% increase in average grain size from 2.66 mm in the Archaic period (4385–1550 cal BP) to 3.56 mm in the Upper Emergent/Protohistoric period (ca. 400–120 cal BP) (2004:128). Hammett noted that the length of *Hordeum* grains from the Talepop site (CA-LAN-229) site in southern California exceeded 4.7 mm, which is substantially larger than previously recorded grains (1991:191, 209).

The California evidence also includes the possibility of a six-row barley. One of the grains from the CA-YOL-182 site discussed above “has an immature, twisted seed adhering to its side at the embryo end” (Miksicek 1999:8). This is the only evidence of this trait presented by Miksicek or any other scholar for California.

Comparison of Evidence for Little Barley Domestication in U.S. Regions

Morphological evidence for Little Barley domestication can be compared among Southwestern, Southeastern/Midwestern, and California regions (Table 2). All regions claim hull-less (naked) grains as a major trait. Increasing grain size through time has been documented for California, and inferred via application of a correction factor applied to charred grains in the Southeastern/Midwestern U.S.

TABLE 2
MORPHOLOGICAL TRAITS PRESENTED BY RESEARCHERS AS EVIDENCE OF *HORDEUM PUSILLUM*
DOMESTICATION IN THREE REGIONS OF THE UNITED STATES

Region	Midwestern US (Middle Mississippi River Valley)	Southwestern US (Central and Southern Arizona)	California
Time periods	Middle/Late Archaic to the prehispanic Oneota periods	Late Archaic through the Hohokam Classic periods	Archaic through the Mission periods
Hull-less (naked) grains	Grains lack paleas and lemmas; limited evidence of transverse wrinkling on ventral face	Grains lack paleas and lemmas	Grains lack paleas and lemmas
Larger grain size	Yes; increasing grain size through time	Not discussed	Yes; increasing grain size through time
Shift from a two-row to a six-row form	Limited evidence of grains that are twisted		One example of a grain that appears twisted
Non-shattering rachis		Limited evidence of rachis fragments that have not separated	
References	Asch and Asch (1985); Hunter (1992); Simon and Parker (2006); Smith (1992a)	Adams (2014); Bohrer (1984, 1987, 1991)	Hammett (1991); Miksicek (1999); Reddy (2009, 2015); Wohlgemuth (2004); Wohlgemuth et al. (2015a, 2015b)

This trait has not been recorded in the Southwestern U.S. except in limited instances. When it comes to a shift from two rows of fertile florets to six rows of fertile florets, limited evidence exists for this condition in the Southeastern/Midwestern U.S., and a single potential example has been reported from California. The Southwestern U.S. reports limited evidence of a non-shattering rachis.

A New Record of Little Barley in Southwest Colorado

A new record of domesticated Little Barley in a southwestern Colorado Ancestral Puebloan archaeological context notably increases its known geographic range hundreds of miles northeast of the central and southern Arizona Hohokam region (Figure 4). Two charred, domesticated *Hordeum pusillum* grains were found in flotation samples excavated from a hearth feature in a Basketmaker III pit house at the Switchback Site (5MT2032) in Montezuma County, Colorado. Their size in mm, 1.892 (length) × 1.092 (width) × 0.761 (thickness) and 1.829 × 1.054 × 0.775, fits within the range of other charred domesticated specimens from central and southern Arizona (Adams 2014:148). These two grains are recognizable as a domesticated species due to their hull-less condition. Both grains display no evidence of the palea and lemma that once surrounded and protected them as they matured on the plant (Figure 3).

The Switchback Site is located not far from the Four Corners city of Cortez, Colorado. Located at an elevation of 6,200 ft, the site was prehistorically and is currently surrounded by a piñon (*Pinus edulis*) and juniper (*Juniperus osteosperma*) woodland. The excavated portions of the Switchback Site included a pit house, a slab-lined storage room, and a few middens (Sommer et al. 2015).

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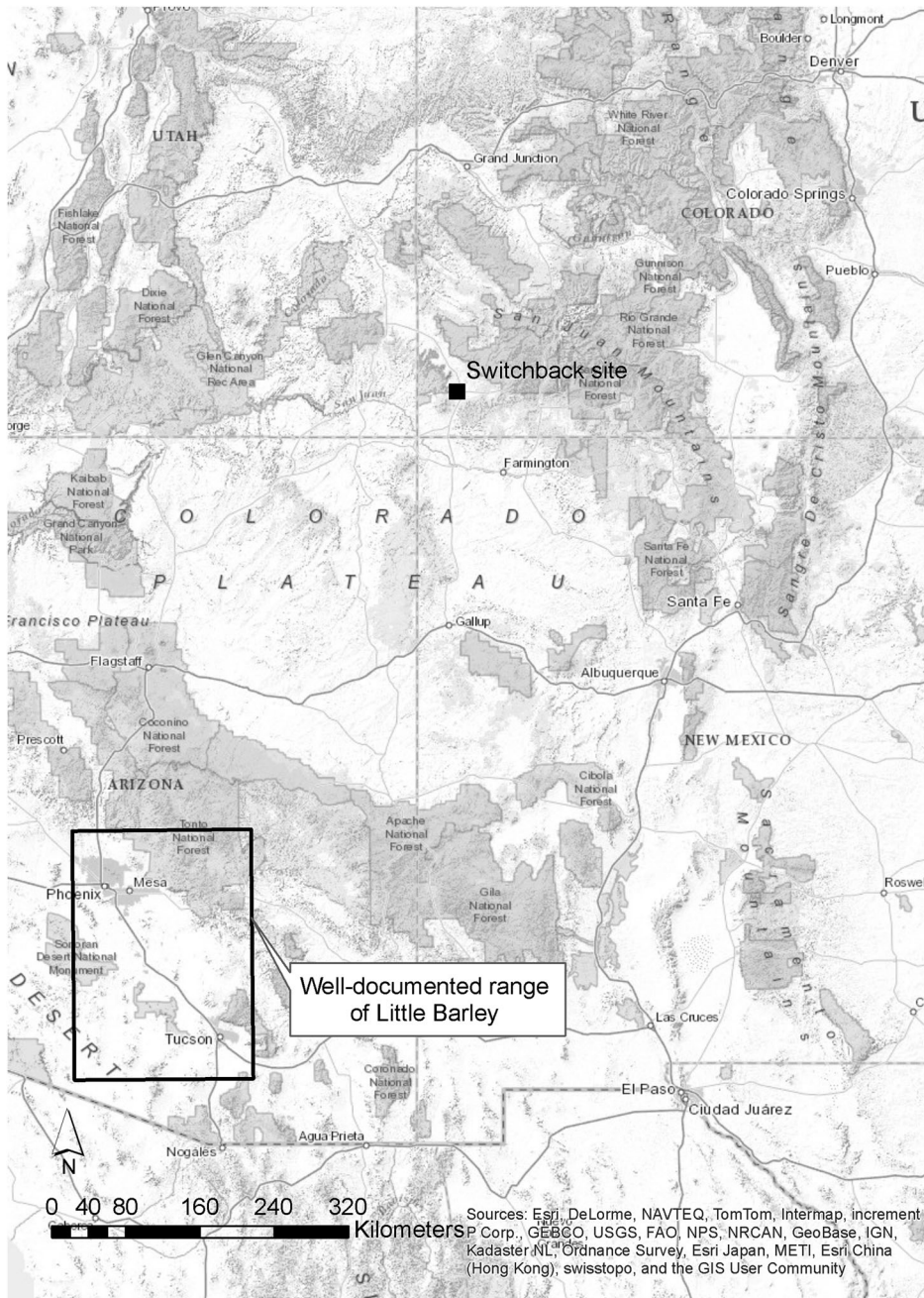


FIGURE 4. Map showing the Switchback Site in relation to the previously known range of domesticated Little Barley.

The hearth and pit house where the two Little Barley grains preserved offer a unique context in that neither feature was cleaned out when ancient occupants moved away. A radiocarbon date from the floor level associated with the latest deposits in the

hearth is calibrated to AD 750 ± 48, which places these grains and the people using them in the latter part of the Basketmaker III period. Associated plant parts within the hearth feature offer a picture of a diverse subsistence record. Specimens of Mesoamerican domesticates including maize or corn (*Zea mays*) and common beans (*Phaseolus vulgaris*), recovered within another context in the same structure, indicate that the inhabitants were farmers. However, a variety of other native food remains including seeds of amaranth (*Amaranthus* sp.), ground cherry (*Physalis* sp.), and tansy mustard (*Descurainia pinnata*), along with sunflower (*Helianthus annuus*) achenes (fruit), indicate that people were preparing wild plant resources as well. The presence of both domesticates and wild plant foods within the hearth provide supportive evidence that the associated Little Barley grains also represent a food product.

One significant advantage of Little Barley in the U.S. Southwest is its late winter/early spring availability. *Hordeum*, along with other genera, are cool season grasses (Bohrer 1975), sprouting in the winter and ripening in the spring, a season when food stores have been depleted, and long before summer crops are ripe. The value of these resources cannot be understated, as they fill a critical time in which groups had few other subsistence resources to turn to. Having a domesticated cool season plant, such as Little Barley, bridged a particularly food-stressed time of year.

Another advantage is the nutritional components present in the grains. Using Old World domesticated barley (*Hordeum vulgare*) as a guide, and based on a 2,000-calorie daily food allowance, 100 gm (3.53 ounces) of Little Barley could provide approximately 24.3% of the recommended total daily carbohydrates, 22.4% of protein, and 18% of calories, plus other dietary constituents (Watt and Merrill 1975).

Simple explanations of the domesticated Little Barley grains within the Switchback Site include travel or trade. Contact with Hohokam groups in central and southern Arizona may have led to acquisition of *Hordeum pusillum* by groups living in southwestern Colorado, where further cultivation may or may not have resulted. This scenario could be explored via groundwater isotope tracing analysis as has been applied to maize in Chaco Canyon (Benson et al. 2003). Some Switchback occupants may have even traveled to the Hohokam region to harvest the domesticated Little Barley grains themselves.

A Consideration of Independent Domestication in Southwestern Colorado

Comparing/contrasting morphological traits indicating domestication of Little Barley in different U.S. regions, discussed above, does not strongly support or refute cases for independent Little Barley domestication(s) in one or more of these major U.S. regions. To assess if the new southwest Colorado evidence might represent domestication independent from that of the Hohokam in central and southern Arizona, other types of “plausibility arguments” considered here include: the role of relatively simple (one or few) mutations responsible for hull-less grains and the six-row condition; the possibility of polyploidy, which is a multiplication of chromosomes leading to larger plants and potentially larger harvests; a case for

domestication that includes pollen grain evidence; and the propensity of ancient farmers to manage/cultivate other wild plants such as agaves (*Agave*), revealing that they were already familiar with the process of changing wild plants to suit their needs. Another developing approach includes molecular assessments of modern Little Barley populations for comparison between the major U.S. regions, as well as to ancient uncharred Little Barley specimens.

Single/Few Mutations

In the Old World, two morphological changes resulting in domesticated barley have been tied to simple mutations, revealing how a single gene change can make a huge difference to human groups. The first change, a shift from a protected to a hull-less (naked) grain, occurred via a reasonably mutable gene. This hull-less condition was observed in wild populations a number of times historically (Harlan 1979:27; Stubbe 1959). Hull-less grains would lose protection from predators and environmental extremes; however, human management substituted for the role of protector. The second change, development of a six-row barley leading to an increase in grain yield, also appears to have occurred via a mutation controlled by a single recessive gene at the *vrs1* locus (Tanno 2014:281–282). That such a simple mutation occurs on occasion was demonstrated by Bohrer (1977:13), who observed a wild six-row *Hordeum pusillum* plant growing in west-central New Mexico in a modern iris bed free of competing weedy plants. Such an unusual plant would be easy to recognize, collect, and propagate.

One or a few mutations can also explain two traits of maize domestication, the premier crop in the ancient Southwest. Apparently, a single nucleotide change was responsible for a major morphological shift from an encased kernel (grain) in ancestor teosinte (*Zea mays* L. ssp. *parviglumis*) to the naked kernel of domesticated maize (*Zea mays* L. ssp. *mays*) (Wang et al. 2015). A stand of wild teosinte plants with grains that required minimal processing may have attracted attention, to become a founder population for what is now a major worldwide crop. In a similar vein, recurrent mutations appear to have led to repeated development of sweet kernels in maize (Tracy et al. 2006). Analysis of fifty-seven modern sweet corn cultivars revealed only five independent mutations, with three of the five represented by single mutations (base pair changes).

Another relevant case of independent domestication of a crop in the New World is that of common beans (*Phaseolus vulgaris*), now considered to have been domesticated separately in both Mesoamerica and the Andean region (Chacón et al. 2005). Morphological and isozyme evidence for this was confirmed by a molecular analysis of chloroplast DNA polymorphisms. The archaeological bean record currently suggests that common bean domestication in the Andes may have occurred a few thousand years prior to a separate Mesoamerican domestication (Kaplan and Lynch 1999).

Polyploidy

A mutation to a polyploid condition would potentially produce larger plants with larger parts that could have attracted human attention. Polyploidy refers to a

numerical change in a set or sets of chromosomes. For example, a tetraploid plant contains four copies of an individual chromosome ($4N$) instead of only one from each parent, which is the normal diploid ($2N$) condition. Polyploidy may occur during cell division, either via mitosis or meiosis; polyploidy is so pervasive in plants that estimates suggest 30–80% of living plant species are polyploid, and may have been so in ancient times (Meyers and Levin 2006; Otto 2007; Rieseberg and Willis 2007). Researchers have suggested that 15% of angiosperm speciation events are accompanied by a ploidy increase (Wood et al. 2009). The diploid form of *Hordeum pusillum* is $2N = 14$ chromosomes (Covas 1949:2; Löve 1980:166). However, one Little Barley plant specimen collected near Granite Reef Dam in central Arizona was reported to possibly be a tetraploid form, based on the larger size of both stomata (microscopic epidermal pores) and pollen grains (Covas 1949:14). Other genetic studies support the link between larger pollen grains as an expression of polyploidy mutations (De Storme et al. 2013; Knight et al. 2010:3).

Grass Pollen Grain Size

A discussion of Little Barley plant domestication could include larger than average grass pollen grains, suggesting some level of human management in the past. All of the grasses, including maize (*Zea mays* L.), produce round pollen grains with one pore ringed by an annulus of variable thickness and width. A gradient of decreasing grass pollen grain diameters is separated into three general categories, detailed below, that discriminate the cultivars from wild grasses. However, without other supporting criteria, pollen grain size alone is an unreliable trait for fine taxonomic identifications, because size can be affected by genetic and environmental factors, laboratory procedures, and, for fossil grains, age (Fægri and Iversen 1989:233–235; Kurtz et al. 1960).

In the Southwest U.S., palynologists use both pollen grain and pore diameters to classify grass pollen as: (a) maize, (b) “large grass” type, and (c) all other grasses (Smith 1998, 2009). Maize pollen grains are the largest with diameters greater than 60 microns, followed by “large grass” Old World cereal grasses (oats, barley, wheat, and rye – *Avena*, *Hordeum*, *Triticum*, and *Secale*) with diameters between 40 and 60 microns and with annulus (pore) diameters generally greater than 10 microns, and then by wild grass pollen grains at less than 40 microns in diameter (Anderson 1979; Fægri and Iversen 1989:284–286; Moore et al. 1991:100). The intermediate “large grass” category also includes three native Southwest genera, Little Barley (*Hordeum*), panic grass (*Panicum*), and Indian ricegrass (*Achnatherum hymenoides*).

In the case of the Colorado Switchback Site, no “large grass” pollen grains were identified from five pollen samples collected within two of the structures (Smith 2015a). However, at four archaeological sites near the Switchback Site, large grass pollen that could represent *Hordeum* is documented in 12 samples out of 103 samples analyzed (Smith 2015b, 2016a). The four sites are the large Basketmaker III Dillard Site (5MT10647) and three smaller sites: the Pueblo II Badger Den Site (5MT10686), transitional Basketmaker III to Pueblo II Shepherd Site

(5MT3875), and the Portulaca Point Basketmaker III site (5MT10709). Ten of the 12 samples with large grass pollen grains are from interior structure floors or features, including at the Dillard Site, two samples from a Great Kiva – one from a floor and the second from the southern sipapu where large grass pollen co-occurs with maize pollen. Interestingly, pollen studies from this region of southwestern Colorado hint at a chronological pattern in the occurrence of large grass pollen. Currently large grass pollen has been identified primarily in Basketmaker III contexts, and in only a single Pueblo age sample (a posthole in a midden at the Pueblo II Badger Site), based on 44 samples analyzed from seven Pueblo II to Terminal Pueblo III architectural sites including the large Goodman Point Pueblo (Smith 2016a, 2016b, 2016c).

Familiarity with Plant Domestication

The developing argument for independent domestication of Little Barley in SW Colorado has precedent in the Southwestern U.S. Hohokam region, where researchers have listed a number of wild plants demonstrated or likely to have come under some form of human management (Bohrer 1991; Doolittle and Mabry 2006; Fish and Nabhan 1991). For example, in Arizona there are cases of numerous independent *Agave* domestications. Starting with *Agave parryi* in the Mogollon region (Minnis and Plog 1976) and *Agave murpheyi* in the Hohokam region of southern Arizona (Fish et al. 1985; Fish and Fish 2014), archaeologists first recognized some of these plants as relict (legacy) populations from ancient management. Archaeological evidence for *Agave murpheyi*, including rock pile fields, associated roasting pits, and specialized artifact types such as agave knives and snub-nosed scrapers, coupled with discussions of agave management in the historic era, provide a strong case for agave management in prehistory (Fish et al. 1985; Fish et al. 1992; Fish and Fish 2014). *Agave murpheyi* plants flower like other agaves, but instead of producing fruit with seeds, they produce bulbils (tiny agaves) in the flowering stalk, a condition attractive to a farmer interested in spreading the young plants into rock pile fields. The fact that the bulbils do not fall from the parent plant naturally, but must be physically broken off by humans to be planted (Adams and Adams 1998:16), suggests such a plant would not have persisted long in the wild. However, humans took over the role of propagator. If human groups were interacting with agaves and other wild plants, their familiarity with the process and results of domestication could have easily been transferred to or from Little Barley. Other researchers continue to present evidence of additional agave species domesticated in the U.S. Southwest in ancient times (Hodgson 2006; Hodgson and Salywon 2012, 2013; Parker et al. 2007, 2010).

A Molecular Approach

Increasingly, evidence to demonstrate independent domestication will be made via molecular analyses. It is already known there were two independent centers of domestication for barley in the Old World: Near East/Fertile Crescent region and Tibet (Dai et al. 2012). The same molecular studies revealed that the Chinese hull-less (naked) and six-row barleys were clearly derived from the Tibetan barley domesticates.

A molecular approach to reveal similarities/differences between modern populations of *Hordeum pusillum* in North America has begun. Distinguishing among populations of a single species can be more difficult than discerning one species from another, or one genus from another. The longer the period of genetic separation, the more mutations can accumulate to distinguish taxa at the molecular level. Initial efforts focused on modern wild Little Barley plants collected from Midwestern and Southwestern U.S. locations: Tyson Research Center, St. Louis Co., MO; Kings Ditch Bayou, Arkansas Co., AR; Mule Creek, NM; and Bloody Basin Road, Perry Mesa, AZ. An on-line genetics resource, the NCBI GenBank DNA sequence database, provided additional comparative data, as did two other New World species, *H. brachyantherum* and *H. jubatum*, an Old World species *H. murinum*, and unrelated domesticated wheat (*Triticum aestivum*).

Comparisons of DNA sequences focused on three plastid genome sites: those coding for leucine transfer RNA (*trnL*); ribosomal DNA (*rDNA*); and the intergenic transcribed sequence (*ITS*). The sequences compared included 975 base pairs. The *trnL* genes showed very little differentiation among the sequences available. For the *rDNA* gene, in conjunction with additional data (Baum and Johnson 2000), there was a considerable degree of differentiation (Figure 5). The populations from New Mexico, Arizona, Missouri, and Arkansas grouped together and with GenBank samples from CA, IL, and northern AZ. Furthermore, there was no clear distinction between the sequences of *H. pusillum* and two other *Hordeum* species, including the Old World species *H. murinum*. The *ITS* gene sequence revealed significant differentiation (Figure 6). Twenty-seven sites showed differences among *H. pusillum* samples. The *ITS* gene sequence was identical in some sample pairs (New Mexico and Arizona; Missouri and Arkansas), and other differences were minor. A tentative conclusion is that the distribution of *H. pusillum* around North America may represent spread, possibly through trade, during or after the period of genetic differentiation. This study lays initial groundwork to characterize modern Little Barley populations in regions where evidence exists for ancient Little Barley domestication.

One drawback is that molecular analyses are currently not possible on charred materials. Although most Little Barley evidence in the Southwest U.S. is charred (Adams 2014), some is not. For example, uncharred Little Barley planting units were mixed in with raw cotton (*Gossypium*) and other miscellaneous debris at the Tonto National Monument Upper Ruin, originally described by Bohrer (1962:113) and subsequently re-examined by Adams (1987:206–209). One provenience (Area A, Lab No. 3122) was recovered from an interior, protected location (Steen 1962:1). This uncharred Tonto collection currently at the Western Archaeological and Conservation Center of the National Park Service (Tucson), could provide ancient specimens for molecular analysis.

Multiple Lines of Evidence: The Perry Mesa Arizona Example

Cases for management/domestication are always strengthened when more than one line of evidence is presented. In the Northern Hohokam Periphery, Bohrer reported 33 carbonized hull-less Little Barley grains from a rock shelter site near a 40-room

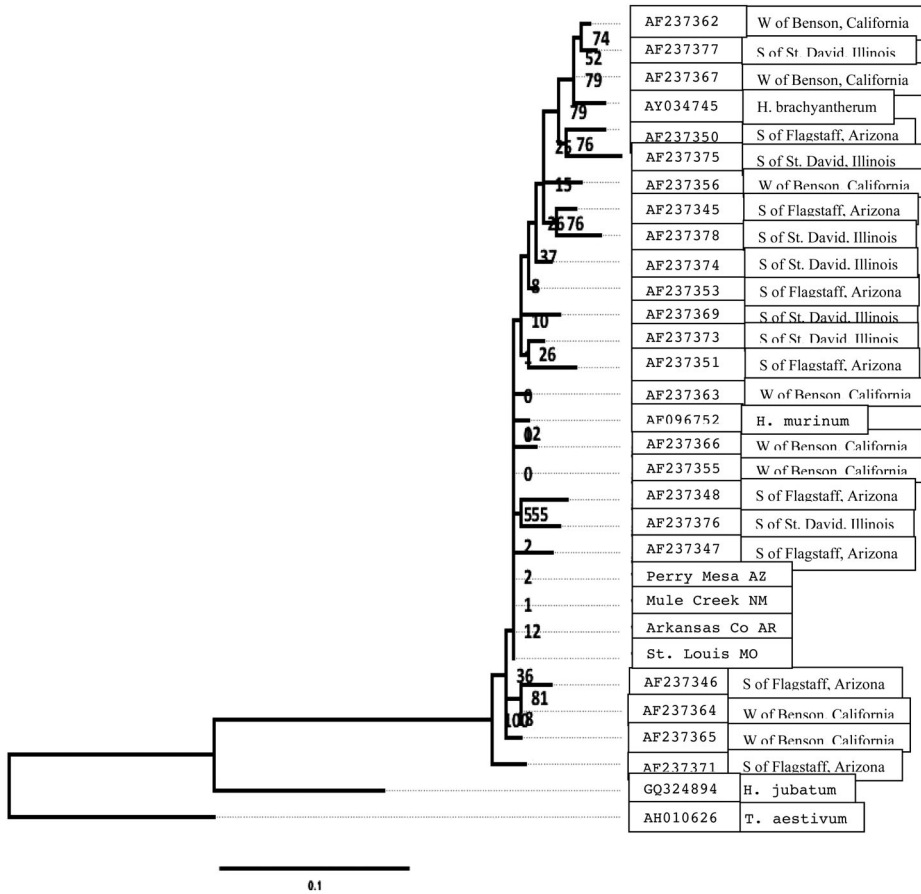


FIGURE 5. Comparison of partial plastid *rDNA* (*Ribosomal DNA*) gene sequences (256 bases) of *H. pusillum* from multiple U.S. sites (Perry Mesa, AZ; Mule Ck, NM, St. Louis, MO; Arkansas Co, AR), *H. murinum* (GenBank reference AF096752), *H. jubatum* (GQ324894), and *Triticum aestivum* (AH010626).

pueblo (1984:249) on Perry Mesa (north of Phoenix, AZ). More recently, Smith (2009) documented large grass pollen grains in 16 of 38 samples collected from agricultural terraces and inter-terrace spaces from the same general Perry Mesa area. In Smith’s study, microscopic measurement of 41 of the large grass pollen grains yielded the following summary statistics (grains preserved in glycerol): average diameter 51 microns (range 45–58 microns) and average pore plus annulus diameter 11 microns (range 8–13 microns). When fall/winter moisture has been adequate, Perry Mesa can still be covered by Little Barley populations ripening in the spring-time (Figure 7). The prehistoric Perry Mesa Little Barley domestication evidence includes both naked grains and larger than usual size pollen grains, similar to the evidence presented here for the new southwestern Colorado record. The Little Barley plants there today may represent either the founder population or an *in situ* legacy population from ancient human management efforts. To acquire

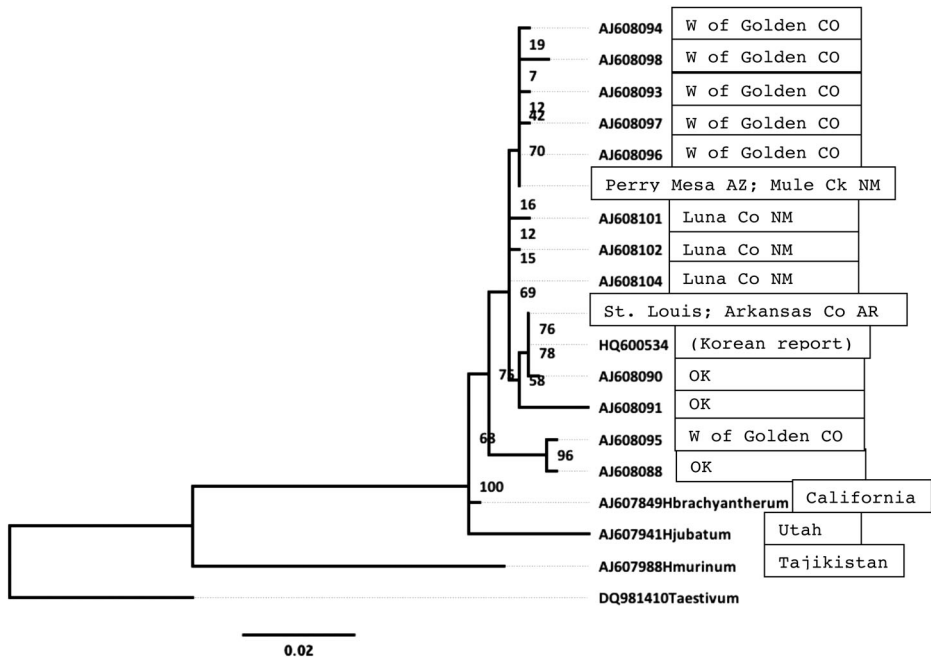


FIGURE 6. Comparison of partial plastid *ITS* (*Internal Transcribed Sequences*) gene sequences (596 bases) of *H. pusillum* from multiple U.S. sites (plus one Korean reference), *H. pusillum* samples (Perry Mesa, AZ; Mule Ck, NM; St. Louis, MO; Arkansas Co, AR), *H. brachyantherum*, *H. jubatum*, *H. murinum*, and *Triticum aestivum*.

information relevant to this hypothesis, a recent effort by Adams and Smith to harvest and examine 50 bags of mature Little Barley plants on Perry Mesa revealed no modern plants with hull-less grains, or six (instead of two) fertile florets, or a non-shattering rachis. Additional collecting trips are needed to confirm these results.

Other Considerations

In the Southwestern U.S., Little Barley evidence in archaeological sites is documented only as fully domesticated grains. As a cool season grass, the wild form could have been important even prior to its domestication. This case has not yet been made. Because grass grains within archaeological sites are often identified only to the family level, it is not known with certainty if Little Barley grains with paleas and lemmas still attached (the wild form) were gathered and processed prior to domestication.

Predominantly, the record of managed, cultivated, and domesticated indigenous plants is best developed in the Hohokam region of the U.S. Southwest. Efforts should be made to evaluate evidence of other wild plants that occur frequently in the Southwest U.S. archaeological record, and that have been listed as likely candidates by others (Bohrer 1991; Doolittle and Mabry 2006; Fish and Nabhan 1991).

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FIGURE 7. Left: Karen Adams and Susan Smith harvesting ripe Little Barley grass on Perry Mesa, April 17, 2016. Little Barley is the low, tan-colored grass surrounding them and mixed in with other grasses and plants. Right: dense Little Barley plants on Perry Mesa. Photos by Rex K. Adams.

Discussion

The discovery of two charred domesticated Little Barley grains in southwestern Colorado is a first for the region. This find is important for understanding regional pre-history and broader subsistence patterns, with direct relevance for understanding the late Basketmaker III population of Montezuma County as groups were beginning the transition to the Pueblo I time period. The lack of previous reports of domesticated Little Barley in the vast archaeobotanical literature of this area may be due to its limited presence or use, or to as yet unidentified *Hordeum pusillum* grains in assemblages characterized at the broad level of grass (Poaceae) grains.

This find is hundreds of miles from the well-known central/southern Arizona Hohokam region where the story is well documented. Like other domesticates that existed in prehistory, Little Barley did not make it to the historic era. Domesticated plants have been developed and lost within human subsistence regimes for thousands of years. The morphological evidence for Little Barley domestication in the Southwestern U.S. is similar to that in the Southeastern/Midwestern U.S. and California. All three regions include hull-less grains. In the Southwestern U.S. Hohokam region, additional evidence includes limited examples of non-shattering rachis (flowering stem) parts, and larger than average pollen grain size that could indicate a managed or domesticated wild grass. The California and Southeastern/

Midwestern evidence includes two additional traits, such as increasing size of Little Barley grains over time, and limited evidence for a six-row variety.

Single to multiple origins of domesticated Little Barley cannot be declared on the basis of existing morphological or range distribution evidence. This new discovery of Little Barley in Southwestern Colorado, far from central and Southern Arizona, does not clarify the issue. Until Little Barley remains are reported from other sites in other time periods, the Colorado Switchback Site hull-less Little Barley grains remain an intriguing example of a past human-plant relationship that may have been limited in scope and duration. Groundwater isotope tracing analysis and/or molecular analyses could shed more light on the issue of any relationships between Little Barley in Colorado, in central and southern Arizona, and in other major regions of the United States. Molecular studies, initiated here for modern plants from a variety of locations, should continue and be expanded to include well-preserved non-charred prehistoric specimens.

Little Barley was an important ancient food for a number of reasons. It offered a late spring resource in a normally food-stressed time of year. It provided nutritional constituents similar to those of the modern barley of commerce. The plant is widely distributed across North America, and is already at home on the continent. Little Barley may well be resilient in the face of environmental (i.e. global warming) and biotic (insects and other predators) changes by virtue of its adaptation here over millennia. Although it appears that prehistoric domesticated Little Barley was fading from the list of human foods during protohistoric and historic eras, it could conceivably be redomesticated by observant humans surveying wild populations.

Today barley (*Hordeum*) and maize (*Zea mays*) are among the most important world-wide grain crops. It appears that relatively simple and potentially recurring genetic changes (mutations) in the wild ancestors of these crops played a critical role in human domestication efforts. The presence of two domesticated Little Barley grass grains within the southwestern Colorado late Basketmaker III period Switchback Site, coupled with larger than average grass pollen grains in nearby sites, together suggest a more intensive Little Barley human-plant relationship not previously documented outside of central and southern Arizona.

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Supplementary Material

For Supplementary material accompanying this paper, visit [10.1080/00231940.2017.1376261](https://doi.org/10.1080/00231940.2017.1376261).

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