

Diversity In Andean *Chenopodium* Domestication: Describing A New Morphological Type From La Barca, Bolivia 1300-1250 B.C

Author(s): BrieAnna S. Langlie, Christine A. Hastorf, Maria C. Bruno, Marc Bermann, Renée M. Bonzani, and William Castellón Condarco

Source: Journal of Ethnobiology, 31(1):72-88. 2011.

Published By: Society of Ethnobiology

DOI: <http://dx.doi.org/10.2993/0278-0771-31.1.72>

URL: <http://www.bioone.org/doi/full/10.2993/0278-0771-31.1.72>

BioOne (www.bioone.org) is a nonprofit, online aggregation of core research in the biological, ecological, and environmental sciences. BioOne provides a sustainable online platform for over 170 journals and books published by nonprofit societies, associations, museums, institutions, and presses.

Your use of this PDF, the BioOne Web site, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at www.bioone.org/page/terms_of_use.

Usage of BioOne content is strictly limited to personal, educational, and non-commercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

DIVERSITY IN ANDEAN *CHENOPODIUM* DOMESTICATION: DESCRIBING A NEW MORPHOLOGICAL TYPE FROM LA BARCA, BOLIVIA 1300-1250 B.C.

BrieAnna S. Langlie, Christine A. Hastorf, Maria C. Bruno, Marc Bermann,
Renée M. Bonzani and William Castellón Condarco

The domestication of Chenopodium in the Andean altiplano of South America was a complex process that took place during the Formative period (1800 B.C.-A.D. 400). We identified a new archaeological morphological type of Chenopodium sp. at the La Barca site, located in the Department of Oruro, Bolivia. We analyzed testa texture, margin configuration, beak prominence, seed diameter, and testa thickness using scanning electron microscopy. As a member of the same genus as Chenopodium quinoa, the identification of this new anthropogenic morphotype presents us with insights into the many complexities of the process of domestication and points towards selection occurring in multiple regions and different culture groups.

Key words: *Domestication, Chenopodium, paleoethnobotany, La Barca, quinoa*

La domesticación de Chenopodium fue el resultado de un complejo proceso que ocurrió durante el periodo Formativo (1500 a.C - 400 d.C) en el altiplano andino de America del Sur. Se ha identificado un nuevo tipo morfológico de Chenopodium sp. en el yacimiento arqueológico de La Barca, ubicado en el Departamento de Oruro, Bolivia. Se examinó la textura de la testa, configuración del margen, prominencia del pico, diámetro de la semilla, y grosor de la testa de este nuevo tipo morfológico del mismo género que Chenopodium quinoa con un microscopio electrónico de barrido. Su identificación de este nuevo tipo permite comprender mejor su complejo proceso de domesticación y sugiere que hubo presiones selectivas en varias regiones y por parte de distintos grupos culturales.

A major theme of archaeological research has been to understand the transformations that we associate with the Neolithic Revolution, the increasing interdependence of humans, plants and animals, or the domestication of living things. This specific dependency process played a central role in the history of human-nature relationships as interactions between these organisms and the spaces they share were modified. It is important to understand these transformations because they represent changes in plant taxa and their ecologies, and they inform us about peoples' decisions regarding their food supplies and their interactions with the landscape (Cusack 1984). The complex history of

BrieAnna S. Langlie, Department of Anthropology, Washington University in Saint Louis, Saint Louis, MO (e-mail: blanglie@wustl.edu)

Christine A. Hastorf, Department of Anthropology, University of California-Berkeley, Berkeley, CA (e-mail: hastorf@berkeley.edu)

Maria C. Bruno, Department of Anthropology, Washington University in Saint Louis, Saint Louis, MO (e-mail: mcbruno@artsci.wustl.edu)

Marc Bermann, Department of Anthropology, University of Pittsburgh, Pittsburgh (e-mail: bermarc@pitt.edu)

Renée M. Bonzani, Department of Anthropology, University of Kentucky, Lexington, Kentucky (e-mail: renee.bonzani@uky.edu)

William Castellón Condarco, Proyecto Arqueológico Wankarani Oruro, Bolivia (e-mail: williamcastell@gmail.com)

interdependency between plants and humans differs in each region and for each plant.

The highland Andes of South America has long been recognized as a center of crop domestication (Cook 1925; Vavilov 1992:402–404). Early inhabitants of this region domesticated several tuber species (*Solanum tuberosum* L., *Solanum stenotomum* Juz. & Bukasov., *Oxalis tuberosa* Molina, *Tropaeolum tuberosum* Ruiz & Pav., and *Ullucus tuberosus* f. *albiflorus* Kuntze) and at least two pseudocereals (*Chenopodium quinoa* Willd. and *Chenopodium pallidicuale* Aellen). Despite this region's importance to agricultural history, the archaeological record still has much to teach us about the process of domestication in the Andes (Hastorf 2006). For example, genetic research is beginning to shed light on where certain crops were domesticated (Emshwiller 2002, 2006; Spooner et al. 2005; Wilson 1988a), but archaeological investigations of Andean crops can illustrate how and in which cultural settings these crops spread to other regions (Hastorf 2006).

The Bolivian Department of Oruro, located in the south-central *altiplano* is home to one of the most important Early Formative period (1800-1000 B.C.) agropastoral populations, known in the archaeological literature as the Wankarani (Janusek 2008:20; Ponce 1970). This period is when mobile hunter-gatherers settled into sedentary life ways in the *altiplano*. Documenting the patterns of chenopod use in the Formative period helps our understanding of the domestication process as well as the adoption of agriculture in the south-central Andes. Ponce (1970) was the first investigator to suggest that chenopods played an important role in the Wankarani agro-pastoral adaptation, although his reconstruction of agriculture in the region was based on the identification of agricultural tools, rather than archaeobotanical evidence. In this paper, we present the first morphological investigation of early archaeological chenopods from this region and for this cultural group.

Here, we add to the growing body of information regarding the process and timing of *Chenopodium* domestication in the Andes by presenting evidence for a previously unrecognized, possibly domesticated chenopod. We describe a sample of archaeological *Chenopodium* seeds from the site of La Barca (Figure 1), using morphological attributes. We then compare these seeds to published descriptions of modern *Chenopodium* species from the northern region of the *altiplano* (Bruno 2001, 2006; Bruno and Whitehead 2003). Significantly, none of the La Barca specimens are an exact match to the modern specimens. Thus, these data on a new possibly domesticated variety aids in tracing the continuous process of domestication of the different varieties of Andean *Chenopodium*.

Previous morphological studies of *Chenopodium* seeds, particularly those of the domesticate quinoa (*C. quinoa*) show that seeds undergo significant changes in diameter, testa thickness, and shape (margin configuration) during domestication. Morphological studies of South American archaeological chenopods derive mostly from the Lake Titicaca Basin of Perú and Bolivia (Browman 1989; Bruno 2001, 2006; Bruno and Whitehead 2003; Eisentraut 1998) and from the central Peruvian Andes (Nordstrom 1990; Pearsall 1980, 1989). A potential region for its early use and possible domestication is the *altiplano*, the high plain of the central Andean mountain chain, where domesticated chenopods continue to be important subsistence crops and where the majority of today's commercial

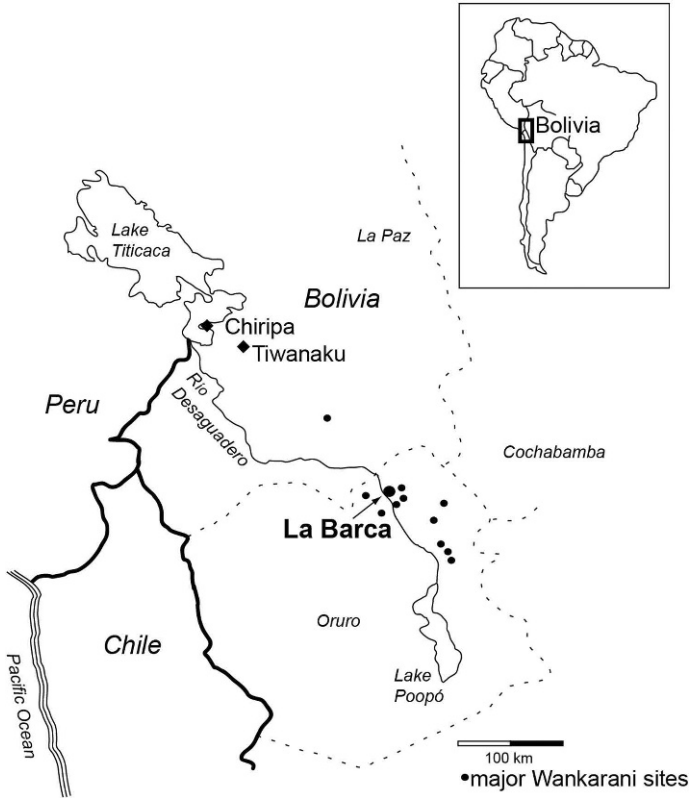


Figure 1. La Barca, Bolivia and surrounding region.

cultivation takes place (Hellin and Higman 2003:90). The cool, dry climate of this region limits the cultivation of many plants, but potatoes and especially *Chenopodium* thrive in the saline soils.

There are six modern *Chenopodium* taxa that play a role in this discussion of Andean chenopod domestication. The best-known and studied taxon is domesticated *Chenopodium quinoa* (quinoa). Its weedy counter-part is commonly referred to as *quinoa negra* (black quinoa) or *ajara*, a name widely applied to wild, black-seeded quinoa-like species throughout the Andes (Wilson 1988b, 1990). Botanists have assigned different designations to *ajara*: *Chenopodium quinoa* var. *melanospermum* Hunziker, *Chenopodium quinoa* ssp. *milleanum* Aellen, and *Chenopodium hircinum* Schrader. Currently, there is no consensus as to whether these are monophyletic and all three are seen in the literature. Here, following Cárdenas (1989), we use *Chenopodium quinoa* var. *melanospermum* because that is most commonly used in Bolivia. A second domesticate, *Chenopodium pallidicaule*, or *kañawa*, has received little study. According to recent botanical descriptions, there are wild/weedy varieties/species of this crop, which the Bolivian taxonomists call *Chenopodium pallidicaule* Aellen var. *pampalasta* (IGPRI et al. 2005).

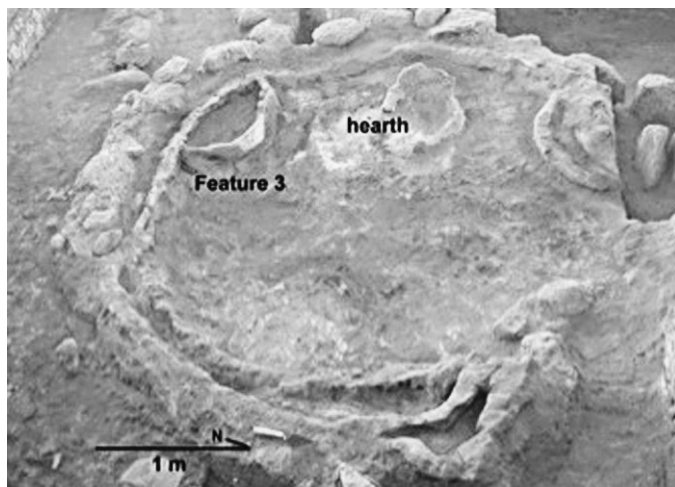


Figure 2. Feature 3 visible inside Structure 04-2-10 at La Barca, Bolivia. Photograph by M. Bermann.

The Wankarani Complex and The La Barca Site

The Wankarani sites of the Formative Period (1800 B.C.–A.D. 400) represent one of the earliest village populations in highland Bolivia. Distributed throughout the southern Department of La Paz and the northern sections of the Department of Oruro, most sites take the form of residential mounds from 0.10 to 9.0 ha in size, located at the base of hills (Bermann and Estévez 1992; Fox 2007; McAndrews 1998, 2001; Ponce 1970, 1980). The site of La Barca (Canton of La Joya, Department of Oruro, Bolivia) is a circular mound built from successive domestic occupations and consisting of house remains, middens, and aeolian deposits (Rose 2001a, 2001b). Covering 0.6 ha, the main portion of the mound is approximately 2.0 m high, rising at the center to 5.0 m. The site's occupation spanned 1500 - 400 B.C., with an estimated residential population at any one time of 50 to 150 residents. Excavations between 2003 and 2005 by Rose and Bermann exposed a series of house compounds. These included one or more small circular dwellings, each 3 – 5 m in diameter, with an interior hearth, attached storage structures, outdoor activity surfaces with hearth and storage features, and associated midden deposits.

The *Chenopodium* analyzed in this study was recovered from an interior storage feature (Feature 3) within Structure 04-2-10. This structure is 3.5 m in diameter, with an eastern entry and a small, attached storage space (Figure 2). Although the structure contained a characteristic Wankarani slab-lined hearth, it differed from typical Wankarani dwellings in several ways. It had double walls: an outer wall consisting of adobe set on a stone foundation, and paralleling this, a second wall made of very thin clay and built over thin wooden poles set vertically into the ground. The interior wall may have formed a partition or low support rather than a roof-high wall. A radiocarbon sample (AA70741) from the wall poles provided a date of 3024 ± 35 ^{14}C years B.P., correlating to a calibrated (CALIB 6.0) one sigma date of 1320 to 1257 B.C. While the structure is possibly

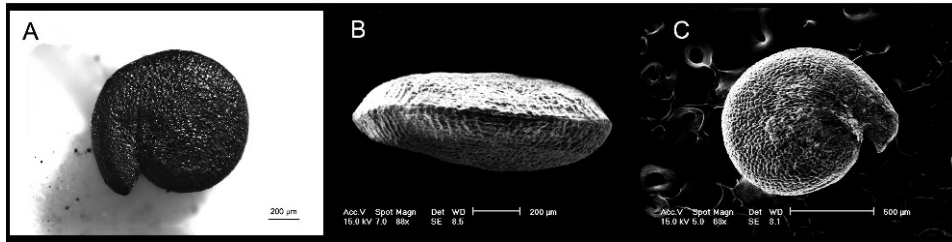


Figure 3. Attributes of archaeological *Chenopodium* from La Barca. A. A light microscope photo that typifies a prominent beak and a reticulate-aveolate testa texture (sample # LB70). B. An SEM image of a biconvex margin configuration and a reticulate-aveolate testa texture (sample # LB74). C. An SEM image of a prominent beak and a canaliculate testa texture (sample # LB108).

part of a residential compound, Bermann and Castellón propose that it was primarily used as a ceramic workshop rather than a dwelling. Floor artifacts included “loaves” of worked unfired clay, chunks of quartz, a vessel containing ground quartz and grinding stones stained with pigment. Additionally, the floor lacked the organic staining and small domestic debris commonly found in dwellings at the settlement.

A curved clay bin (Feature 3) measuring $60 \times 40 \times 20$ cm was built against the interior wall of the structure. This bin showed no evidence of intensive burning or cooking. The analyzed *Chenopodium* seeds were recovered from a 6-liter soil sample taken from the lowest layer of the feature’s fill. This layer was a 14 cm thick, unstratified deposit of silt and ash with charcoal inclusions. A thin layer of post-abandonment aeolian silt and ash covered the structure’s floor, its associated artifacts, Feature 3, and the sampled layer in the feature, thus we are confident that our samples come from undisturbed contexts that date to the Wankarani occupation.

Attributes of *Chenopodium* Seed Morphology

The *Chenopodium* plant produces thousands of dry, single-seeded fruits on panicles that do not shatter easily. At the center of the fruit is a round, starchy perisperm. An embryo wraps around the periphery of the perisperm and terminates with one side (the radicle) extending over the other (the seed leaves) in what is called the beak (Figures 3 and 4). Surrounding both the perisperm and embryo is a covering called the seed coat or testa. This feature has two layers, a very thin inner epidermis that does not vary in size whether the specimen is wild or domesticated, and an outer epidermis, or testa, which does vary, being thinner or even absent in domesticated species (Wilson 1981:Figure 2). A final layer called the fruit coat, or pericarp (this plant part technically qualifies the seed as a fruit), encapsulates the entire structure. Some of these characteristics vary among species.

In this analysis of the La Barca seeds, we consider five attributes to describe and distinguish the *Chenopodium* spp. seeds: testa texture, margin configuration, beak prominence, seed diameter, and testa thickness. The terminology and attributes we use build upon previous research of *Chenopodium* seed morphology, including Aellen and Just (1943), Bruno (2001, 2006), Fritz (1984), Nordstrom

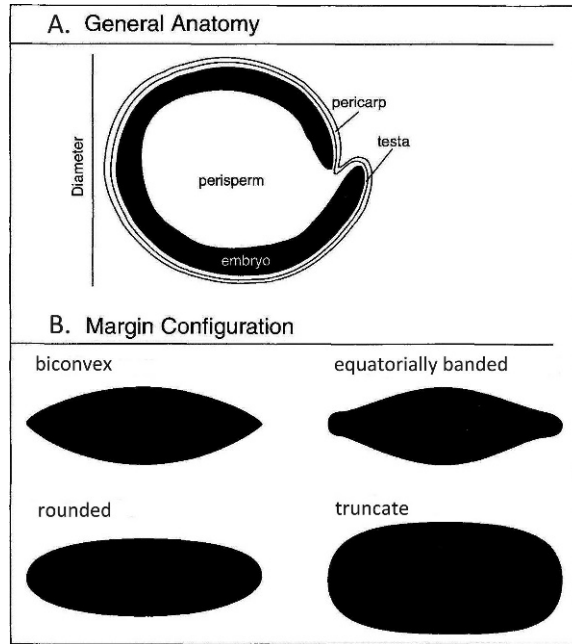


Figure 4. A. *Chenopodium* seed morphology showing diameter measurement. B. Margin configuration shapes applied to the La Barca seeds (From Bruno and Whitehead 2003:342).

(1990), Pearsall (1980), Smith (1984, 1985a, 1985b), and Wilson (1981). In addition, we have added the attribute, beak prominence, which was not described in any of the previous Andean *Chenopodium* studies but has been used effectively in recent Mesoamerican studies (Gordon 2006; Gremillion 1993a). Below, we describe how each of these structures can vary and the methods used to document them. These traits are organized into two indices: qualitative attributes and quantitative attributes.

The Qualitative Index

Testa Texture

The testa and pericarp of *Chenopodium* seeds vary by species and can be useful for identification. In studies of modern species, seed coat surface texture has been used to distinguish domestic from wild species. For example, in the eastern North American and Mexican *C. berlandieri* species, the wild seeds have a reticulate patterning, whereas the seeds of the extinct domesticated eastern North American subspecies *Chenopodium berlandieri* Moq. ssp. *Jonesianum* have smooth testa textures (Fritz 1984; Smith 1984). Eisentraut (1998) and Bruno (2001, 2006) identified a similar trend in the Lake Titicaca Basin species, noting that *Chenopodium quinoa* var. *melanospermum*, the wild variety, has a reticulated testa texture while *C. quinoa*, the domestic crop, has a smooth testa. While other attributes are also useful, the testa texture is the most readily observable, often visible with a light microscope. Bruno (2001, 2006) describes the texture of four species of modern chenopods (*C. pallidicaule*, *C. quinoa*, *C. ambrosioides*, and *C.*

quinoa var. *melanospermum*) from the Lake Titicaca Basin. We applied Bruno's testa texture definitions to this study.

Margin Configuration

Margin configuration describes a seed's profile (Figure 4B). Wilson (1980) and Hunziker (1952) noted variations in the shape of *Chenopodium* margins, in particular, that the cross-section shape of the seed correlates with the thickness (or presence) of the seed coat. When the testa is thick, the shape of the inner structures (perisperm, embryo) is restricted and the two halves of the thick seed coat create a narrow angle along the margin, producing a biconvex shape. In contrast, in a seed with a thin or absent testa, the perisperm and embryo are not restricted and influence the overall shape of the seed, making the margins rounded or truncate. Eisentraut (1998) and Bruno (2001, 2006) used this attribute to highlight the differences between the domestic *Chenopodium quinoa*, which has a truncate shape, and wild *C. quinoa* var. *melanospermum*, which has a biconvex shape (Figure 4). Bruno (2006) used four margin configurations (truncate, round, biconvex, and equatorial banded) to describe the Lake Titicaca modern and archaeological *Chenopodium* seeds from the northern area of the *altiplano*. For this study, we define these four configurations as follows: truncate seeds have a rectangular profile; round seeds are oval in profile; biconvex seeds have margins that come to a point (Figure 3B); and equatorially banded seed configurations are similar to the biconvex profile but with a noticeable thin extension at the margin. We use these types to describe margin configurations of the La Barca seeds.

Beak Prominence

Beak prominence has been applied in only a few studies of morphological variation of *Chenopodium* seeds. In eastern North American samples, weak or non-existent beaks often correlate with wild or weedy *Chenopodium* species (Gremillion 1993b:157), and a prominently beaked chenopod is considered the result of domestication (Asch and Asch 1985:177). Gordon (2006) recently demonstrated the complexity of using beak prominence in analyzing the wild to domestic spectrum of chenopods, because beak prominence does not always correlate with domestication status. For example, the domesticated cultigen from Michoacán, Mexico called *chia* is a chenopod variety that has a weak beak (Gordon 2006:109). Previous Andean studies have not included beak prominence in their analyses, perhaps because modern domestic *Chenopodium* species have a weak to very weak beak configuration. The application of a beak prominence attribute to the Andean *Chenopodium* seeds should enhance our understanding of the domestication process in this area. Following Gordon's (2006) typology, we apply a ranked ordinal four-score system where 0 = very weak beak prominence, 1 = weak beak, 2 = prominent beak, and 3 = very prominent beak (Figure 5).

The Quantitative Index

Seed Diameter and Testa Thickness

In many domesticated cereals, there has been a selection for larger-sized grains due to seedbed competition (Harlan 1975; Harlan et al. 1973). Bruno and

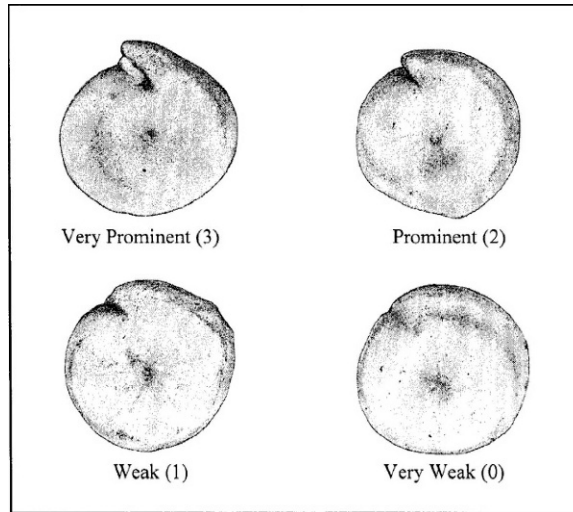


Figure 5. Beak prominence (From Gordon 2006: Figure 5.3).

Whitehead (2003) determined that recovered archaeological domestic quinoa from the Andes is smaller than modern domestic quinoa. This evidence suggests that quinoa increased in grain size due to selection pressures. However, seed diameter alone should not be used to determine the status of archaeological specimens. Maximum and minimum seed diameter ranges are known for each *Chenopodium* species, but there is a significant overlap in the diameters of individual species, making it difficult to identify species solely on the basis of seed diameter. For example Bruno (2001, 2006:39, Figure 4.4) found that when large samples of seeds are considered, there is a marked range in seed size within each Andean species. Similarly, there is an overlap in size among the North American chenopods (Smith 1985a). Here we measure the seed diameter as the distance between two points on the horizontal plane of a seed (Figure 4A). However, because of the overlap between wild and domesticated modern species, we use this measure in conjunction with other attributes.

Testa thickness (Figure 6) is an important quantitative feature in understanding the domestication process of chenopods. Wilson (1981) and Smith (1984, 1985a, 1985b) found a thinner testa to be a diagnostic feature of both eastern North American and Mexican domesticates. They associate this development with competition in seedbed germination (Harlan 1975), as those with a thinner testa germinate more rapidly. *Chenopodium berlandieri* ssp. *Jonesianum*, a domesticated species from eastern North America has a thin testa that measures 0–20 μm in thickness (e.g. Fritz 1990; Smith 1984, 1985a). Similarly, Gordon (2006) found that the Mexican domesticate *chia* has a thin testa that measures 1–20 μm . In modern and archaeological specimens of the Andean domesticate *C. quinoa*, Nordstrom (1990), Eisentraut (1998), and Bruno (2001, 2006) found the seed coat to be absent or very thin (<5 μm). Bruno found that the testas of the domesticate *kañawa* (*C. pallidicaule*) are also very thin (4–8 μm). In contrast, the companion

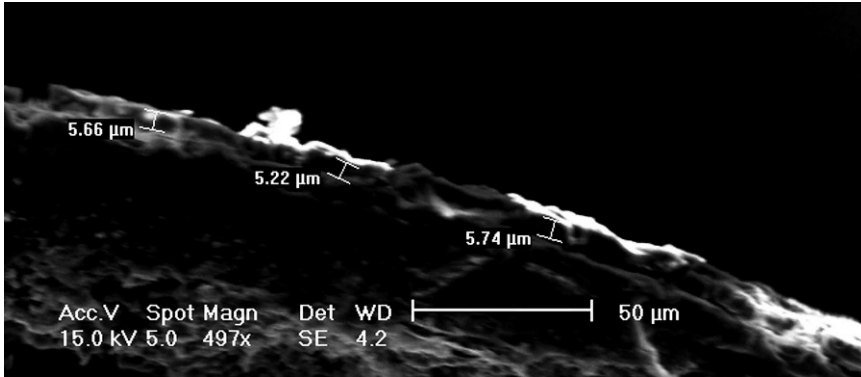


Figure 6. SEM image of testa thickness measurements.

wild variety to domesticated quinoa that often grows in modern fields as a weed, *quinoa negra* (*C. quinoa* var *melanospermum*, *C. quinoa* ssp. *millenium*), has the thickest testa (20–50 μm) thus far identified in the region. The wild Andean species *paiko* (*C. ambrosioides*) has medium thick testa (11–14.5 μm). Given the differences in testa thickness among these Andean *Chenopodium* species, it is useful to consider this attribute in describing archaeological species, and in the case of *C. quinoa*, differentiating wild versus domesticated species. As with diameter, however, testa thickness alone does not distinguish the Andean types because unlike the species studied in North America, there are wild species in the Andes, such as *paiko*, that have testa thickness less than 20 μm .

Bruno (2006) suggests that examining the ratio of testa thickness to seed size is useful for distinguishing individual species. For example, although *paiko* has a relatively thin testa, it also has a very small diameter, thus the testa is quite thick relative to overall seed size (Figure 6). Therefore, relatively thin-testa wild varieties still seem to have relatively thicker testas than associated domestic seeds. By applying this ratio to a domestication study, we can begin to reveal the selection pressures applied to the seeds over time, through both size and shape.

We analyzed the relationship between seed diameter and testa thickness by applying the equation used by Bruno (2006) for her comparison of modern *Chenopodium* species. The testa thickness for each seed is doubled “to account for the entire area represented by the testa” for this measurement (Bruno 2006:Table 4.5). This equation is:

$$\text{Ratio Testa Thickness/Diameter} = \text{Log} (\text{Total testa thickness in } \mu\text{m} \times 2) / \text{Log} (\text{Seed diameter in } \mu\text{m})$$

In this paper, we only analyzed charred seeds. For purposes of comparison, we only compared the La Barca seeds to other Andean chenopod studies that analyzed charred seeds (Bruno 2001; Bruno and Whitehead 2003; Bruno 2006). Smith (1985b) and Nordstrom (1990) found that the diameter of carbonized seeds is about 5% smaller than uncarbonized seeds, but that testa thickness is unaffected by carbonization.

La Barca Chenopod Analysis

Specimen Selection

Bonzani analyzed the macrobotanical remains from the site of La Barca, and sent approximately 200 archaeological *Chenopodium* seeds to Hastorf and Langlie at the University of California-Berkeley Paleoethnobotanical Laboratory for more detailed morphological examination. Specimens for this analysis were selected using light microscopes with a magnification range of 10–40 \times . We selected only relatively undamaged or whole specimens so that we could observe all attributes for each seed. From the 200 seeds, we selected 18 specimens that could be analyzed, and we assigned each seed a unique number. While this is a small sample, we began with this number to test our attributes' robustness as well as to learn about the Wankarani chenopods.

Equipment and Sample Recording

We studied the selected seeds using both light and scanning electronic microscopes equipped with software programs to obtain measurements. Whole seeds were first photographed with an Olympus BX51 light microscope, equipped with a camera in the University of California-Berkeley Paleoethnobotanical Laboratory. Specimens were placed on a glass tray on top of white putty, allowing us to take pictures of the seed lying flat and on edge to view the margin configuration. Using images recorded by this microscope, testa texture, margin configuration, beak prominence, and seed diameter were measured and recorded. To record the seed diameter, we used an interpolated polygon tool to obtain a mean diameter, rather than one measurement.

A scanning electron microscope was essential for analysis of the testa thickness and testa texture. Because testa thickness can only be measured accurately with high magnification scanning electron microscopy (SEM), we employed a Phillips/FEI XL30 Environmental Scanning Electron Microscope (ESEM) located in the Scanning Electron Microscopy Laboratory within the Biomolecular Nanotechnology Department at the University of California-Berkeley (Figures 3B and C). In order to create a clearer image in the ESEM chamber, we sputter coated the specimens with a thin metallic layer of Au/PD in a Tousimis Sputter Coater for 20 seconds.

Testa texture was obtained first on the ESEM by mounting the specimens longitudinally, or flat, exposing the fullest extent of the testa surface. After gathering measurements from this position, the specimens were then remounted and sometimes cut to expose a clear cross-section of the testa. The microscope's tilt function, not available on some SEM machines, was used to reveal the flattest plane possible of the cross section of the testa. From this vantage, we obtained at least three measurements of the testa thickness.

Results

Qualitative Analyses

Of the 18 specimens we analyzed, the testa surface was discernable for only 14 due to excessive fragmentation of 4 seeds. Five seeds have a canaliculate testa

Table 1. The five major attributes for the eighteen La Barca *Chenopodium* seeds in the study.

Seed Diameter (μm)	Margin Configuration	Testa Texture	Testa Thickness (μm)	Beak Prominence
1006.68	Biconvex	Reticulate	4.9	3
1183.29	Biconvex	Reticulate	5.0	3
1089.11	Rounded	No Data	5.5	3
1038.45	Biconvex	Reticulate	4.8	3
1116.65	Biconvex	Reticulate	5.2	3
995.08	Biconvex	Reticulate	5.3	3
1027.18	Biconvex	Reticulate	No Data	2
No Data	Rounded	Canaliculate	11.0	3
No Data	No Data	No Data	11.8	No Data
1152.80	Biconvex	Reticulate	5.1	3
1111.05	Biconvex	Reticulate	4.6	2
1017.47	Truncate	Canaliculate	No Data	3
974.87	Truncate	Reticulate	3.5	3
1069.40	Biconvex	Canaliculate	6.0	3
1020.33	Truncate	Canaliculate	3.7	3
1281.83	No Data	No Data	No Data	No Data
1034.30	Biconvex	Canaliculate	12.4	2
955.34	Biconvex	No Data	6.8	3

texture, and nine have a reticulate-aveolate texture (Table 1; Figure 3). Canaliculate seed coats (Figure 3C) have elongated reticulations with non-elevated margins. Reticulate-aveolate is the opposite pattern, with reticulations that have raised margins (Figure 3A and 3B). Margin configuration was observable in 16 specimens: 11 have a biconvex margin, 3 have a truncate margin, and 2 have a rounded margin. Sixteen of the seeds analyzed have intact beaks: 14 have very prominent beaks (Figure 3A and 3C), while 2 have prominent beaks.

Quantitative Analysis

We measured seed diameter, testa thickness, and compared seed diameter to testa thickness to quantitatively analyze the archaeological seeds. The seed

Table 2. Measurements of seed diameter, testa thickness, and a ratio comparison of testa to seed diameter for the archaeological seeds from La Barca.

Testa Thickness (μm)	Thickness $\times 2$ (μm)	Log Testa Thickness $\times 2$	Seed Diameter (μm)	Log Seed Diameter	Ratio Log Thickness/ Log Diameter
4.88	9.80	0.99	1006.68	3.00	0.33
4.97	10.00	1.00	1183.29	3.07	0.33
5.54	11.00	1.04	1089.11	3.04	0.34
4.81	9.60	0.98	1038.45	3.02	0.33
5.22	10.40	1.02	1116.65	3.05	0.33
5.30	10.60	1.03	995.08	3.00	0.34
5.12	10.20	1.01	1152.80	3.06	0.33
4.60	9.20	0.96	1276.84	3.11	0.31
4.66	9.40	0.97	1017.47	3.01	0.32
3.49	7.00	0.85	974.87	2.99	0.28
6.04	12.00	1.08	1069.40	3.03	0.36
3.75	7.40	0.87	1020.33	3.01	0.29
12.37	24.80	1.39	1034.30	3.01	0.46
6.81	13.60	1.13	955.34	2.98	0.38

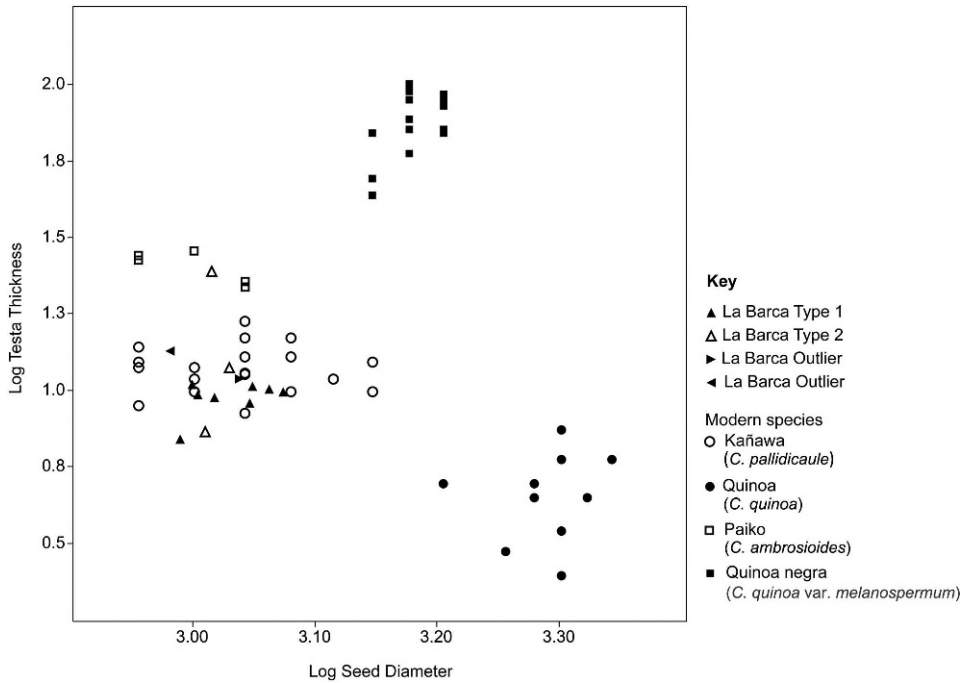


Figure 7. Testa Thickness/Seed Diameter Ratio of the archaeological La Barca *Chenopodium* sp. seeds and Bruno's (2008, Figure 8.12) modern *Chenopodium* varieties.

diameter was obtainable on all 18 specimens (Table 1). Diameters range from 955 to 1282 μm , with a mean of 1087 μm and a standard deviation of 100.6 μm . We present these data in microns to facilitate comparison with the testa thickness. Testa thickness was measurable in 16 specimens, and ranged between 3.5 and 12.4 μm , with a mean of 6.2 μm and a standard deviation of 2.9 μm . The ratio of testa thickness to seed diameter allows us to observe the relative proportion of the seed comprised by the testa. The ratio of testa thickness to seed diameter was calculated for 14 specimens (Table 2).

Discussion

To see how our *Chenopodium* seeds compare to wild and domestic chenopods from the *altiplano*, we plotted the testa thickness/diameter ratios of the La Barca seeds along with those of four modern species examined by Bruno (2006, 2008). The La Barca seeds form a fairly tight cluster defined by a relatively small seed diameter and a thin testa (Figure 7). The testa thickness/diameter ratio reveals that they are most similar to the modern domesticated taxon *kañawa*. While they are much smaller in size and do not have as thin a testa as domesticated modern quinoa, their morphometric similarity to *kañawa* suggests that they fall within the range of a domesticated species.

Despite the similarity of the quantitative measures between the La Barca chenopods and modern-day *kañawa* seeds, there are also notable differences in

their qualitative attributes. Table 1 clearly illustrates that the biconvex margin configuration most often accompanies a reticulate-aveolate testa texture in our archaeological population. These seeds also tend to have very prominent beaks (3). These qualitative attributes are not characteristic of *kañawa*, which generally have a rounded margin configuration and a canaliculate testa texture (Bruno 2006). Although Bruno did not record beak prominence, examination of her photographs (Bruno 2006:Figure 4.7) and available seeds suggest that *kañawa* seeds have only prominent (2) or weak (1) beaks.

A combination of a reticulate-aveolate seed coat and biconvex margin is common in the *quinoa negra altiplano* populations studied by Bruno and Eisentraut, as well as the wild species of eastern North America (Smith1985a). In striking contrast, however, the wild Titicaca Basin populations have very thick seed coats ($>20\ \mu\text{m}$) whereas the La Barca seeds are very thin (3.5–5.5 μm). The prominent beak of the La Barca seeds is uncommon in the wild eastern North American and Mexican chenopods (Gordon 2006; Gremillion 1993a). The *quinoa negra* seeds from the Andes appeared to have a weak beak, based on our comparisons with Bruno's (2006) photographs. Thus, our data suggest that at least nine of the seeds examined in this study represent a very distinct archaeological population of *Chenopodium* that has not previously been reported, and we refer to these as La Barca Type 1.

Four of the seeds are distinct in that they possess a canaliculate testa texture, which is common in modern *kañawa* seeds. In contrast to the domestic *kañawa*, two of the seeds have biconvex margins and two have truncate margins (Table 1). These four seeds differ from *kañawa* with their prominent (2) to very prominent (3) beaks. It is possible that these seeds fall within the range of variability of Type 1; however we refer to them as La Barca Type 2 and suggest that they could represent a descendent of the wild species of *kañawa*. Bruno is currently studying the morphology of wild *kañawa* varieties to clarify the process of its domestication. When those data become available, we may be able to positively identify these four specimens as related to *Chenopodium pallidicaule*. Finally, there were three seeds that could not be fully categorized because we could not assess one or more attributes. Nonetheless, their testa thickness and seed size fell within the parameters of the total La Barca chenopod population, and thus could potentially be variations of Type 1 or Type 2.

Conclusions

The suite of attributes utilized in this analysis provided a more robust way to describe both modern and archaeological *Chenopodium* seeds than previous studies. The analysis of beak prominence as a key attribute had not previously been considered in the study of Andean chenopods. We suggest that this attribute be included along with mean seed diameter, testa thickness, testa texture and margin configuration in future analyses.

The La Barca *Chenopodium* assemblage examined in this study contains at least two distinct morphological types. The most common form, Type 1, has a biconvex margin, a thin reticulate testa, a small diameter, and a prominent to very prominent beak, a combination of attributes that are generally associated

with both wild and domestic modern chenopods. Although this seed type shares some attributes with previously described modern species of the domesticate *kañawa* and the wild *quinoa negra*, it has several unique features that lead us to argue that we have identified a new morphological type. Given that the testa is relatively thin compared to its overall seed size, similar to the proportions of *kañawa*, we hypothesize that this variety may have been a domesticated species that has become feral. We have not yet had the opportunity to collect and study cultivated varieties of domestic *kañawa* and quinoa, or wild varieties of chenopods from the Oruro region, but we hope to do so in the future. Analyzing modern chenopods from the region may permit us to identify this morphotype or an extant relative. It is also possible, however, that like eastern North American domesticated chenopods, this morphotype became extinct. It may have been part of the prehistoric La Barca agro-economy, but was later replaced by other *Chenopodium* domesticates. It is also possible that this archaeological morphotype cross bred with other *Chenopodium* species or varieties, leading to the disappearance of these distinctive combinations of traits from the gene pool as a result of what has been referred to as a “domestication bottleneck on genetic diversity” (Doebly et al. 2006:1310; Wright et al. 2005). The discovery of this unique morphotype certainly warrants further research into the morphological diversity and domestication history of other chenopods as well as continued investigation of the genus in the archaeological sites from the *altiplano*. Our current sample size is very small, so at this stage these conclusions are hypotheses.

The second less common morphological form present at La Barca, Type 2, has a canaliculate surface, a relatively thin testa, biconvex to truncate margin configuration, and a prominent to very prominent beak. It is possible that the combination of these attributes is merely a variant of the La Barca Type 1 species. However, these seeds have much more in common with modern domesticated *kañawa* and are similar to an unidentified morphotype common in samples from Formative sites along the southern Lake Titicaca shore (Bruno 2008:299–306). Bruno’s on-going research on modern *Chenopodium pallidicuale* may soon shed light on this morphotype’s history.

Our data suggests that domestic *Chenopodium* was likely cultivated in the south-central Andes by 1300 B.C. Because seeds morphologically similar to quinoa and *quinoa negra* have been identified in archaeological samples from nearby Lake Titicaca basin located in the northern area of the *altiplano* and date to the same general time period (roughly 1500 - 400 B.C.) (Bruno and Whitehead 2003), we expected to find that the Wankarani were cultivating similar chenopods at La Barca. The absence of those quinoa and *quinoa negra* morphotypes and the presence of a completely distinct, possibly domesticated morphotype (Type 1) suggest that different processes of crop selection, domestication and chenopod use existed in each of these two regions. However, the presence of a *kañawa*-like, possibly wild morphotype in the Lake Titicaca basin suggests some similarity or exchange between the areas. In order to better explain these patterns and link them to the known processes of *Chenopodium* domestication and dispersal, we must continue to excavate sites dating to this important period, systematically recover archaeological plant remains, and

conduct further detailed morphological studies, such as the one described in this paper, on more chenopod specimens.

Overall, the results of this study present a much more complicated picture of Andean chenopod domestication and larger geographic dispersal than was previously envisioned.

Past research by Bruno (2001, 2006) demonstrated that domestic quinoa and wild *quinoa negra* were integral components of early farming systems in the northern *altiplano*, and that they were continually managed and modified throughout the Formative period. This research reveals that the Wankarani people were experimenting with and manipulating different varieties of chenopods during the Formative period. The integration and potential domestication of these distinct *Chenopodium* varieties may have played a crucial role in allowing the Wankarani to successfully settle down in the harsh environment of the south-central *altiplano*. The LaBarca varieties were probably better adapted to the region and the local ecological conditions. Our research suggests that domestication of Andean *Chenopodium* occurred in multiple regions and multiple cultures took part in the process.

Acknowledgements

We thank the team members on both the Taraco Archaeological Project and the Wankarani Project for assisting in this domestication project. Thank you to Dr. Paul Lum, director of the Biomolecular Nanotechnology Department at the University of California-Berkeley, for the use of their SEM machine. Thank you to Eduardo Machicado for the Spanish translation of the abstract. Bruno's research was supported by NSF Dissertation Improvement Grant #0321720, Wenner-Gren Foundation Grant #7073, and a Smithsonian Institution Post-Doctoral Research Fellowship. Finally, we thank the editors and reviewers of this manuscript who gave us cogent suggestions.

References Cited

- Aellen, Paul and Theodor Just
1943 Key and Synopsis of the American Species of the Genus *Chenopodium* L. *American Midland Naturalist* 30:47–76.
- Asch, David L. and Nancy B. Asch
1985 Prehistoric Plant Cultivation in West-Central Illinois. In *Prehistoric Food Production in North America*, ed. Richard I. Ford, pp. 149–203. University of Michigan, Museum of Anthropology Anthropological Papers 75, Ann Arbor.
- Bermann, Marc and J. Estévez Castillo
1995 Domestic Artifact Assemblages and Ritual Activities in Formative Period, Oruro, Bolivia. *Journal of Field Archaeology* 22(3): 389–398.
- Browman, David L.
1989 Chenopod Cultivation, Lacustrine Resources, and Fuel Use at Chiripa, Bolivia. In *New World Paleoethnobotany: Collected Papers in Honor of Leonard W. Blake*, eds. E.E. Voigt and D.M. Pearsall, pp. 137–172. Special Issue Missouri Archaeologist. Missouri Archaeological Society, Columbia.
- Bruno, Maria C.
2001 Formative Agriculture? The Status of *Chenopodium* Domestication and Intensification at Chiripa, Bolivia (1500 B.C.-100 B.C.). Master's thesis (Anthropology) Washington University in Saint Louis, Missouri.
2006 A Morphological Approach to Documenting the Domestication of *Chenopodium* in the Andes. In *Documenting Domestication: New Genetic and Archaeological Paradigms*, eds. Melinda A. Zeder, Daniel G. Bradley, Eve Emshwiller and Bruce D. Smith, pp. 32–45. University of California Press, Berkeley.
2008 WARANQ WARANQA: Ethnobotanical Perspectives on Agricultural Intensifi-

- cation in the Lake Titicaca Basin. Ph.D. dissertation (Anthropology). Washington University in Saint Louis, Missouri.
- Bruno, Maria C. and William T. Whitehead
2003 *Chenopodium* Cultivation and Formative Period Agriculture at Chiripa, Bolivia. *Latin American Antiquity* 14:339–355.
- Cárdenas, Martín
1989 *Manual de Plantas Economicas de Bolivia*. Editorial Los Amigos del Libro, La Paz.
- Cook, Orator F.
1925 Peru as a Center of Domestication: Tracing the Origin of Civilization Through the Domesticated Plants. *The Journal of Heredity* 16(2–3):33–46 & 95–110.
- Cusack, David
1984 Quinoa: Grain of the Incas. *The Ecologist* 14(1):21–31.
- Doebley, John F., Brandon S. Gaut, and Bruce D. Smith
2006 The Molecular Genetics of Crop Domestication. *Cell* 127:1309–1321.
- Eisentraut, Phyllisa J.
1998 Macrobotanical Remains from Southern Peru: A Comparison of Late Archaic-Early Formative Period Sites from the Puna and Suni Zones of Western Titicaca Basin. Ph.D. dissertation (Anthropology). University of California, Santa Barbara.
- Emshwiller, E.
2002 Biogeography of the *Oxalis tuberosa* Alliance. *The Botanical Review* 68(1):128–152.
2006 Origins of Polyploid Crops: The Example of the Octoploid Tuber Crop *Oxalis tuberosa*. In *Documenting Domestication: New Genetic and Archaeological Paradigms*, eds. M.A. Zeder, D.G. Bradley, E. Emshwiller and B.D. Smith, pp. 153–168. University of California Press, Berkeley.
- Fox, Jason
2007 Time and Process in an Early Village Settlement System on the Bolivian Southern Altiplano. PhD dissertation (Anthropology). University of Pittsburgh.
- Fritz, Gayle J.
1984 Identification of Cultigen Amaranth and Chenopod from Rockshelter Sites in Northwest Arkansas. *American Antiquity* 49: 558–572.
1990 Multiple Pathways to Farming in Precontact Eastern North America. *Journal of World Prehistory* 4(4):387–435.
- Gordon, Angela G.
2006 Domesticated *Chenopodium* in North America: Comparing the Past to the Present. Ph.D. dissertation (Anthropology), Washington University in Saint Louis, Missouri.
- Gremillion, Kristen J.
1993a Crop and Weed in Prehistoric Eastern North America: The *Chenopodium* Example. *American Antiquity* 58:496–509.
1993b The Evolution of Seed Morphology in Domesticated *Chenopodium*: An Archaeological Case Study. *Journal of Ethnobiology* 13: 149–169.
- Harlan, Jack R.
1975 *Crops and Man*. American Society of Agronomy, Madison.
- Harlan, Jack R., J.M.J. de Wet, and E. Glen Price
1973 Comparative Evolution of Cereals. *Evolution* 27:311–325.
- Hastorf, Christine A.
2006 Domesticated Food and Society in Early Coastal Peru. In *Time and Complexity in Historical Ecology: Studies in the Neotropical Lowlands*, eds. William Balée and Clark Erickson, pp. 87–126. Columbia University Press, New York.
- Hellin, Jon and Sophie Higman
2003 *Feeding the Market: South American Farmers, Trade and Globalization*. Kumarian Press, London.
- Hunziker, Armando T.
1952 *Los Pseudocereales de la Agricultura Indígena de América*. Acme, Buenos Aires.
- IPGRI, PROINPA, and IFAD
2005 *Descriptores para Cañahua (Chenopodium pallidicaule Aellen)*. Instituto Internacional de Recursos Fitogenéticos, Roma, Italia; Fundación PROINPA, La Paz, Bolivia; International Fund for Agricultural Development, Roma, Italia.
- Janusek, John W.
2008 *Ancient Tiwanaku: Case Studies in Early Societies*. Cambridge University Press, Cambridge.
- McAndrews, Timothy L.
1998 Early Village-Based Society and Long-Term Cultural Evolution in the South-Central Andean Altiplano. PhD dissertation (Anthropology) University of Pittsburgh.
2001 Organización y Crecimiento de los Sistemas de Asentamiento Tempranos Basados en Aldeas en el Altiplano Andino sur Central. In *El Período Formativo en Bolivia: Regiones y Sociedades*, eds. Rivera, Casanovas C., M. Michel López and J. Capriles Flores, pp. 135–146. *Textos Antropológicos* 13(1–2). Universidad Mayor de San Andrés, La Paz.

- Nordstrom, Carol
 1990 Evidence for the Domestication of *Chenopodium* in the Andes. Report to the National Science Foundation. Paleoethnobotany Laboratory Reports #19, University of California, Berkeley.
- Pearsall, Deborah M.
 1980 Ethnobotanical Report: Plant Utilization at a Hunting Base Camp. In *Prehistoric Hunters of the High Andes*, ed. J. Rick, pp. 191–231. Academic Press, New York.
- 1989 Adaptation of Prehistoric Hunter-Gatherers in the High Andes: The Changing Role of Plant Resources. In *Foraging and Farming*, eds. D.R. Harris and Gordon C. Hillman, pp. 318–332. Unwin Hyman, London.
- 2008 Plant Domestication and the Shift to Agriculture in the Andes. In *The Handbook of South American Archaeology*, eds. H. Silverman and W.H. Isbell, pp. 105–120. Springer Science+Business Media, LLC, New York.
- Piperno, Dolores R. and Deborah M. Pearsall
 1998 *The Origins of Agriculture in the Lowland Neotropics*. Academic Press, New York.
- Ponce Sanginés, C.
 1970 Las Culturas Wankarani y Chiripa y su Relación con Tiwanaku. *Academia Nacional de las Ciencias* 25. Academia Nacional de las Ciencias, La Paz.
- 1980 *Panorama de la Arqueología Boliviana*. Juventud, La Paz.
- Rose, Courtney E.
 2001a Household and Community Organization of a Formative Period, Bolivian Settlement. PhD dissertation (Anthropology), University of Pittsburgh.
- 2001b Organización Residencial en una Aldea del Período Formativo Temprano: El Sitio Wankarani de La Barca, Oruro. In *El Período Formativo en Bolivia: Regiones y Sociedades*, eds. Rivera Casanovas, C., M. Michel López and J. Capriles Flores, pp. 147–166. *Textos Antropológicos* 13(1–2). Universidad Mayor de San Andrés, La Paz.
- Smith, Bruce D.
 1984 *Chenopodium* as a Prehistoric Domesticate in Eastern North America: Evidence from Russell Cave, Alabama. *Science* 226: 165–167.
- 1985a The Role of *Chenopodium* as a Domesticate in Pre-Maize Garden Systems of the Eastern United States. *Southeastern Archaeology* 4:51–72.
- 1985b *Chenopodium berlandieri* ssp. *Jonesium*: Evidence for a Hopewellian Domesticate From Ash Cave, Ohio. *Southeastern Archaeology* 4:107–133.
- 2006 Documenting Domesticated Plants in the Archaeological Record. In *Documenting Domestication: New Genetic and Archaeological Paradigms*, eds. Melinda A. Zeder, Eve Emshwiller and Bruce D. Smith, pp. 15–14. University of California Press, Berkeley.
- Spooner, David M., Karen McLean, Gavin Ramsay, Robbie Waugh, and Glenn J. Bryan
 2005 A Single Domestication for Potato Based on Multilocus Amplified Fragment Length Polymorphism Genotyping. *Proceedings of the National Academy of Sciences* 102(41):14694–14699.
- Vavilov, Nikolai I.
 1992 *Origin and Geography of Cultivated Plants*. Translated by D. Löve. Cambridge University Press, New York.
- Wilson, Hugh D.
 1980 Artificial Hybridization Among Species of *Chenopodium* sect. *Chenopodium*. *Systematic Botany* 5:253–263.
- 1981 Domesticated *Chenopodium* of the Ozark Bluff Dwellers. *Economic Botany* 35: 233–239.
- 1988a Quinoa Biosystematics I: Domesticated Populations. *Economic Botany* 42:461–477.
- 1988b Quinoa Biosystematics II: Free-Living Populations. *Economic Botany* 42:478–494.
- 1990 Quinoa and relatives (*Chenopodium* sect. *Chenopodium* subsect. *Cellulata*). *Economic Botany* 44(Supplement):92–110.
- Wright, Stephen, Irie Vroh Bi, Steve G. Schroeder, Masanori Yamasaki, John F. Doebley, Michael D. McMullen, and Brandon S. Gaut
 2005 The Effects of Artificial Selection on the Maize Genome. *Science* 308:1310–1314.