CHENOPODIUM CULTIVATION AND FORMATIVE PERIOD AGRICULTURE AT CHIRIPA, BOLIVIA

Maria C. Bruno and William T. Whitehead

The emergence of agriculture during the Formative period in the southern Lake Titicaca Basin played a crucial role in the development of the region's first complex societies. Our study of Chenopodium *seeds from the site of Chiripa, Bolivia, sheds light on some of the small-scale processes contributing to the development of agricultural systems between 1500 B.C. and A.D. 100. Using a combination of scanning electron and light microscopy, we identified the crop/weed complex of the domesticate, quinoa (*C. quinoa *Willd.), and its weedy relative,* quinoa negra *(*C. quinoa *var.* melanospermum *Hunziker), at Chiripa by 1500 B.C. Analyses of quinoa/*quinoa negra *morphometry and seed frequencies suggest that during the Early Formative period, farmers maintained gardens where both the crop and weed grew and were harvested for consumption. Around 800 B.C., however, we find samples almost entirely of quinoa at Chiripa's social and political center, the Montículo. The paucity of* quinoa negra *seeds suggests that Middle Formative period farmers became more meticulous cultivators of quinoa, perhaps through weeding, careful seed selection, and construction of fields. This study complements previous investigations of settlement patterns, landscape modification, and stone tool use in this region, providing a richer understanding of Formative period agriculture.*

El surgimiento de la agricultura en la cuenca sur del lago Titicaca fue esencial para el desarrollo de las primeras sociedades complejas. Se presenta un estudio de las semillas de Chenopodium *del sitio Chiripa, Bolivia, el cual permite aclarar algunos procesos particulares del desarrollo de la agricultura. Con el uso combinado de microscopio electrónico de barrido (MEB) y microscopía de luz, se identificaron semillas del complejo cultivo/hierbas adventicias de quinoa (*C. quinoa *Willd.)/quinoa negra (*C. quinoa var. melanospermum *Hunziker) alrededor del año1500 a.C. Análisis adicionales de la morfología y la frecuencia de las semillas, revelan cambios significativos. En el período Formativo Temprano (1500 a.C.--800 a.C.) los agricultores tenían jardines donde el cultivo y la hierba adventicia crecían juntas y ambas eran cosechadas para su consumo. Alrededor del año 800 a.C. en excavaciones del centro ceremonial, El Montículo, se encontraron muestras con pocas semillas de* quinoa negras *y muchas semillas de quinoa. La deficiencia de semillas de* quinoa negra *sugiere que los agricultores del período Formativo Medio (800 a.C.–100 d.C.) se dedicaron al cultivo exclusivo de quinoa tal vez utilizando nuevas técnicas de cultivo como el desyerbe, la selección cuidadosa de semillas y la construcción de campos para los cultivos.*

The development of grain (*Chenopodium quinoa*, *C. pallidicaule*) and tuber (e.g., *Solanum tuberosum*, *Oxalis tuberosum*, *Tropaeolum tuberosum*) agriculture played a central role in the emergence of complex societies during the Formative period (1800 B.C.–A.D. 500) in the Lake Titicaca Basin of the Andes (Albarracín-Jordan 1996; Bandy 2001; Browman 1980, 1981; Erickson 1988, 2000; Janusek and Kolata 2002; Kolata 1986, 1996; Stanish 1994, 2003) (Figure 1). Previous studies of settlement patterns, raised fields, and stone tools suggest that agricultural production increased as the region's first villages and civic-ceremonial centers were established (Albarracín-Jordan and Mathews 1990; Bandy 2001; Erickson 1988,1996; Graffam 1990; Kolata and Ortloff 1996; Lémuz-Aguirre 2001; Stanish 1994, 1999; Stanish et al. 1997). These investigations demonstrate that early farmers increased plant food production using large-scale strategies such as exploitation of fertile ecozones, creation of raised fields and terraces, and intensified use of stone digging implements region-wide.

Modern Andean farmers, however, employ a wide range of small-scale strategies to improve agricultural production, including careful seed selection, maintenance of diverse crop varieties, weeding, fertilization with dung or other organic

Maria C. Bruno ■ Department of Anthropology, Washington University in St. Louis, MO 63130
William T. Whitehead ■ Department of Anthropology, University of California, Berkeley, CA 94720

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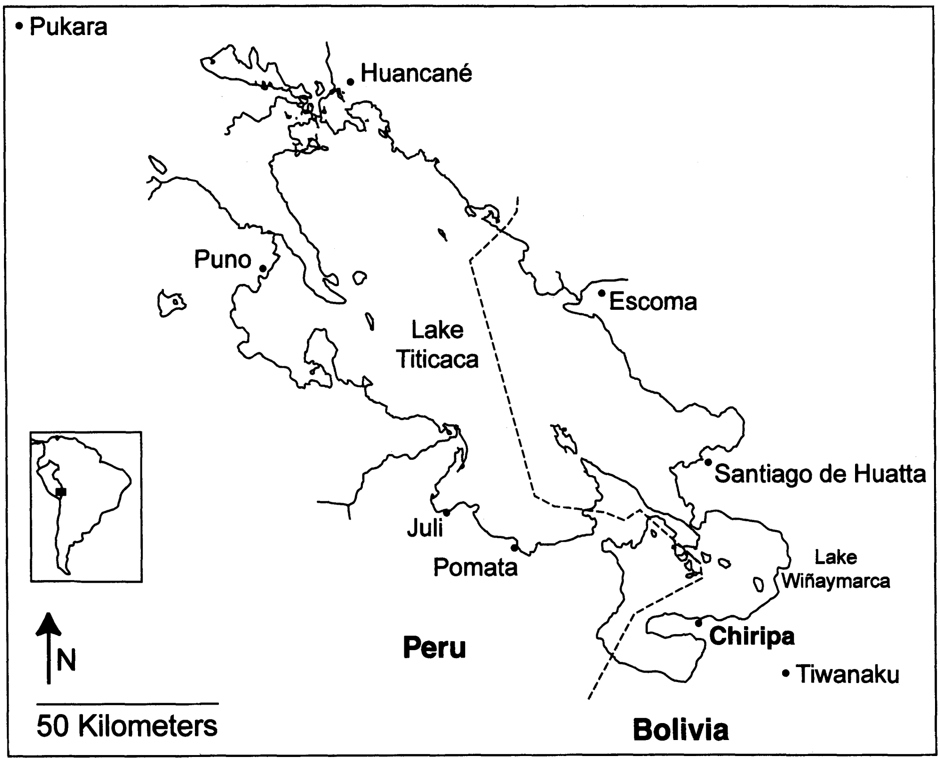

Figure 1. Map of the Lake Titicaca Basin.

material, crop rotation, and fallowing (e.g., Brush et al. 1981; Cardenas 1989; Carter and Mamani 1982; Fonesca and Mayer 1988; Gose 1994; Orlove and Godoy 1986). The development of such small-scale farming practices likely contributed to early food production in the Lake Titicaca Basin. Therefore, examination of such processes in the archaeological record may improve our understanding of Formative period agricultural intensification and its relationship to increasing sociopolitical complexity. We discuss changes in Formative period crop selection and management via a study of charred *Chenopodium* seeds recovered from the site of Chiripa, Bolivia (1500 B.C.–A.D. 500) (Figure 2).

The seeds of *Chenopodium* provide an excellent opportunity for investigating small-scale cultivation practices. Quinoa (*Chenopodium quinoa* Willd.) ranks as one of the most important Andean crops, both now and in the past (Advisory Committee on Technology and Innovation 1989; Hunziker 1952; Risi and Galwey 1984; Tapia Vargas 1976). Available data suggest it was domesticated ca. 3,500 years ago in the south-central Andes (Aldenderfer 1999; Bruno 2003; Eisentraut 1998; Kuznar 1993; Pearsall 1992), and it is ubiquitous in botanical remains from Formative period sites (Browman 1986; Eisentraut 1998; Erickson 1976; Lennstrom et al. 1991a, 1991b, 1992; Pearsall 1992; Towle 1961; Whitehead 1999a, 2003; Wright et al. 2002). Most importantly, *Chenopodium* can provide a wealth of information regarding ancient agricultural practices, as human manipulation of the plant is reflected in its seeds.

Quinoa and *Quinoa Negra* Ecology and Morphology

Chenopods are "ecologically weedy, " a description that refers to colonizing plants adapted to disturbed environments. Many such species are tolerated or even encouraged (Baker 1972; de Wet and Harlan 1975; Holnzer and Numata 1982). Three categories of "weedy" plants are wild, weed, and domesticate (de Wet 1973; de Wet and Harlan 1975; Harlan and de Wet 1965). These categories represent "a continuous series of stages" that differ "in degree of their intimacy with man" (de Wet and Harlan 1975:99). "Wild" plants propagate spontaneously, e.g., *paiko* (*C. ambrosioides* L.), a

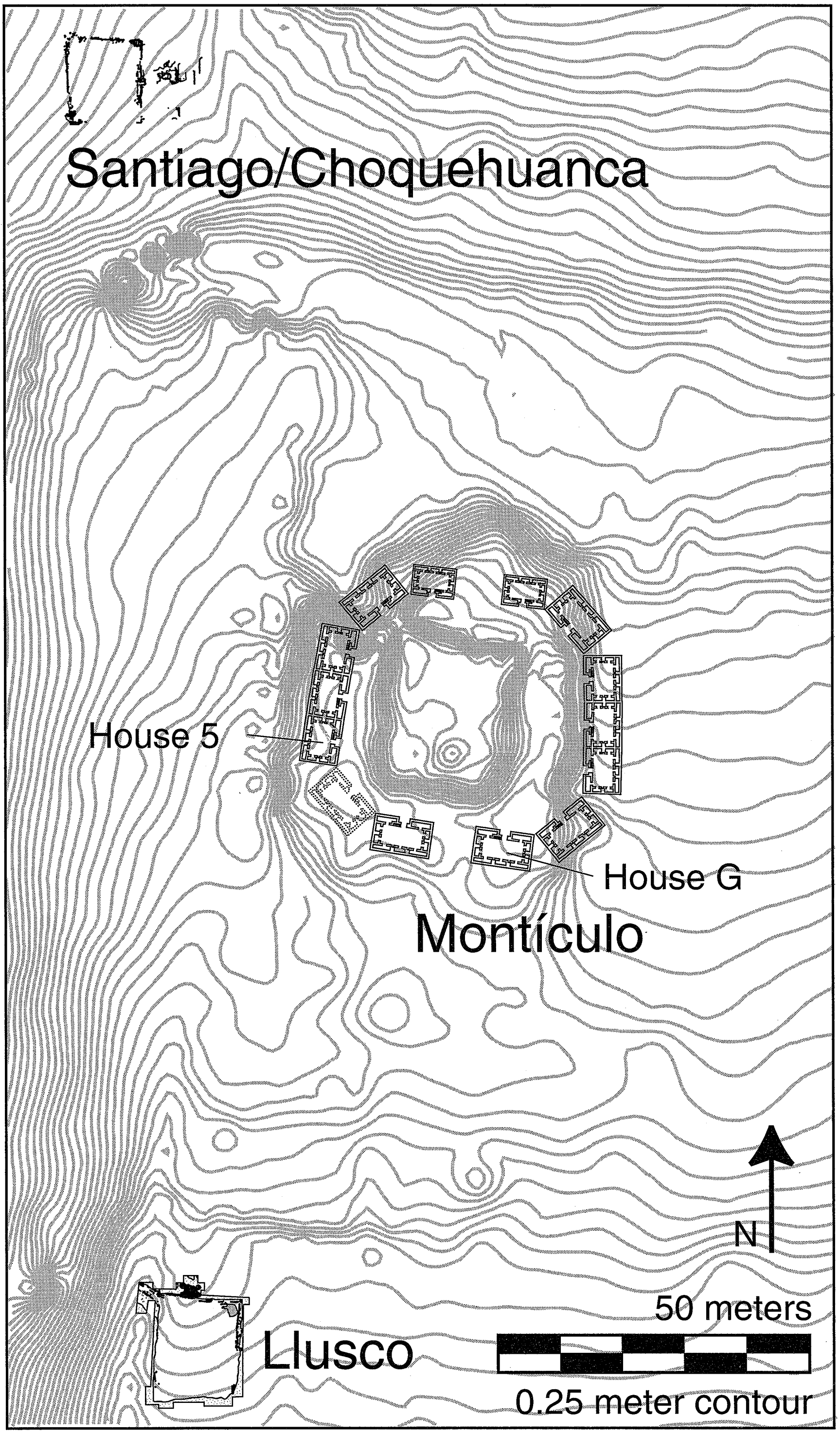

Figure 2. Site map of Chiripa.

medicinal chenopod that grows throughout Andean South America (La Barre 1959). In contrast, "domesticates" such as quinoa (*C. quinoa*) and *kañawa* (*C. pallidicaule* Aellen) have lost their natural dispersal mechanisms and depend on humans for survival. Between these two extremes, the intermediate category "weed" refers to free-living plants highly adapted to human environments such as fields, paths, or roadsides.

In many cases, a "domesticate" and a "weed" evolve together from a common progenitor population, resulting in a "crop/weed complex" (Harlan and de Wet 1975:106). The crop and weed grow within the same anthropogenic habitat, but vary morphologically in response to human and natural selective pressures. The most common *Chenopodium* crop/weed complex in the Lake Titicaca Basin is quinoa (*C. quinoa*) and *quinoa negra* (*C. quinoa* var. *melanospermum* Hunziker) (Cardenas 1989; Gandarillas 1974; Hunziker 1943, 1952; Nelson 1968; Pickersgill 1977; Wilson 1988a, 1990). Quinoa is the well-known Andean crop plant. It grows .5–2 m tall, with broad, lance-shaped leaves, and a large infructescence bearing hundreds of pale seeds ranging from white to yellow and red. *Quinoa negra* is a similar looking plant that grows spontaneously in and around agricultural fields. It is distinguished from quinoa by a more compact infructescence and its black seeds (Cardenas 1989; Hunziker 1952; Wilson 1990).

Taxonomic and genetic studies suggest that quinoa and *quinoa negra* evolved sympatrically from a single wild progenitor population, which remains unidentified (Nelson 1968; Ruas et al. 1999; Wilson 1988a, 1988b, 1988c, 1990). Morphological studies of the quinoa crop/weed complex will be useful for unraveling the question of domestication, but here we emphasize their utility in understanding later process of agricultural intensification (Harris 1989).

Differentiating Quinoa and *Quinoa Negra* Based on Seed Morphology

With the aid of microscopy, paleoethnobotanists have identified micro-morphological seed attributes that permit the identification of various *Chenopodium* taxa, particularly wild versus domestic varieties (Browman 1986; Bruno 2003; Eisentraut 1998; Fritz and Smith 1988; Gremillion

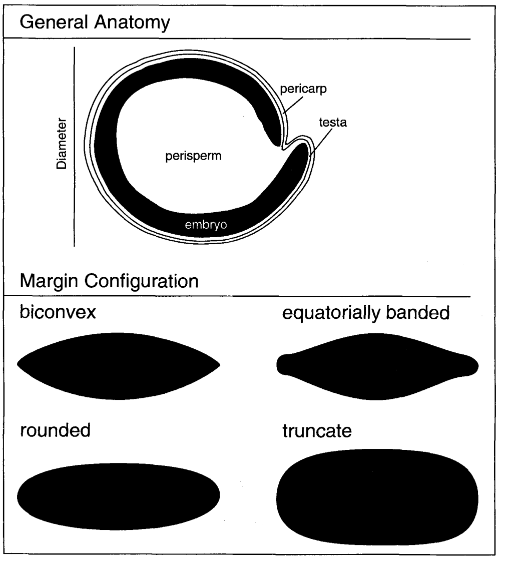

Figure 3. *Chenopodium* seed morphology.

1993a, 1993b; Nordstrom 1990; Pearsall 1980, 1989; Smith 1984, 1985a, 1985b; Wilson 1981). The *Chenopodium* fruit has a starchy perisperm and an embryo that wraps around its perimeter (Figure 3). A membranous layer, called the testa or seed coat, encapsulates the perisperm and embryo. Surrounding the testa is another thin layer called the pericarp, which is the ripened ovary wall. Using scanning electron microscopy, researchers working on North American chenopods found that the domesticated species *C. berlandieri* ssp. *jonesianum* has a thin testa (< 1–20 microns), whereas wild and weedy species including *C. berlandieri* ssp. *berlandieri* have a thicker testa (25–80 microns) (Smith 1985a, 1988; Wilson 1981). Because testa thickness controls germination dormancy, these differences suggest that farmers selected seeds that sprouted quickly.

This trend is also present in Andean chenopods. In modern specimens collected from the southern Lake Titicaca Basin of Bolivia (Bruno 2001, 2003)[1] and central highlands of Peru (Nordstrom 1990), quinoa testa thickness ranges from 1–20 microns, while *quinoa negra* testa thickness ranges from 22–51 microns. Testa thickness is acknowledged as the most diagnostic indicator of *Chenopodium* domestication (Nordstrom 1990:15; Smith 1985a:60), although seed size or diameter also has

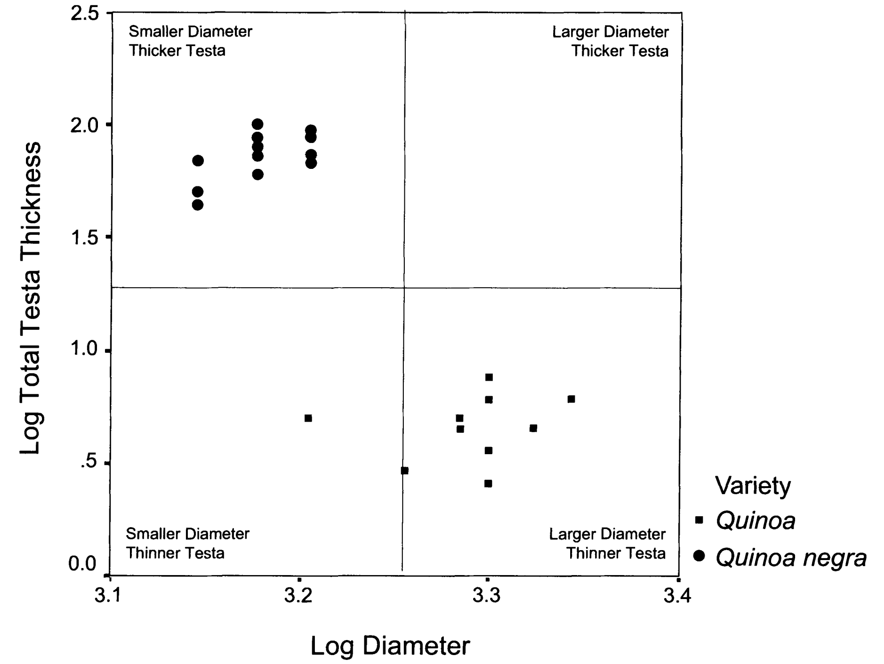

Figure 4. Scatterplot of log testa thickness and log diameter of modern quinoa and *quinoa negra* seeds from the southern Lake Titicaca Basin, Bolivia.

been considered (Asch and Asch 1977; Browman 1986; Pearsall 1980, 1989; Smith 1985a). In North America, diameters of wild and domestic seeds overlap significantly; therefore, size is not considered a diagnostic attribute for this area (Asch and Asch 1977:22; Smith 1985a:59). In samples from the southern Lake Titicaca Basin and highland Peru, quinoa is slightly larger (1.05–2.95 mm) than *quinoa negra* (1.06–1.93 mm), but the overlap is too great to distinguish them in archaeological contexts (Bruno 2001:84; Nordstrom 1990:11).

A ratio of testa thickness to seed size best illustrates the morphometric differences between Andean *Chenopodium* varieties by taking into account both metric variables (Bruno 2001; Nordstrom 1990). The scatter plot in Figure 4 represents the relationship of testa thickness to diameter of modern seeds collected from Aymara farmers in the southern Lake Titicaca Bolivia, Bolivia (Table 1). The quinoa seeds ($n = 11$) have testa thickness/seed diameter ratios of low values, reflecting both larger seeds and thinner testas. Conversely, *quinoa negra* seeds ($n = 16$) have high-value ratios reflecting smaller seeds with thicker testas. These differences are statistically significant ($t = -29.5$; $df = 25$; $p < .001$) and are comparable to testa/diameter ratios of the crop/weed complex in central Peru (Nordstrom 1990:16, Figure 8).

Nonmetric morphological traits of the crop and weed quinoas are also distinctive (Asch and Asch 1977; Bruno 2003; Eisentraut 1998; Smith 1985a, 1985b; Wilson 1980, 1981). Margin configuration varies: quinoa seeds are truncate, whereas *quinoa negra* seeds are biconvex, rounded, or equatorially banded (Figure 3). Seed-coat texture is distinctive: quinoa seeds are smooth whereas *quinoa negra* seeds are reticulate-alveolate (webbed-pitted) (Figure 5). The smooth surface and truncate margins of quinoa are thought to be the result of the reduced testa (Wilson 1981).

These morphological distinctions permit us to identify both quinoa and *quinoa negra* in the archaeological record. The presence and morphological attributes of quinoa varieties are direct indicators of human management. Therefore, examination of the crop/weed complex across time and space allows us to track changes in past agricultural practices (Gremillion 1993a, 1993b).

Table 1. Summary Data for Modern Quinoa and *Quinoa Negra* Specimens from the Southern Lake Titicaca Basin, Bolivia. Examined Under SEM.

Testa Thickness (microns)	Total Testa Thickness (microns)[a]	Log[b] Total Testa Thickness	Seed Diameter (mm)	Log Seed Diameter	Ratio Testa/ Diameter	Log Ratio Testa/ Diameter[c]	Texture	Margin Configuration
				Modern Quinoa				
3.00	6.00	.78	2.20	3.34	.003	-2.56	Smooth	Truncate
1.25	2.50	.40	2.00	3.30	.001	-2.90	Smooth	Truncate
2.25	4.50	.65	2.10	3.32	.002	-2.67	Smooth	Truncate
2.50	5.00	.70	1.60	3.20	.003	-2.51	Smooth	Truncate
2.50	5.00	.70	1.90	3.28	.003	-2.58	Smooth	Truncate
3.75	7.50	.88	2.00	3.30	.004	-2.43	Smooth	Truncate
2.50	5.00	.70	1.90	3.28	.003	-2.58	Smooth	Truncate
2.25	4.50	.65	1.90	3.28	.002	-2.63	Smooth	Truncate
3.00	6.00	.78	2.00	3.30	.003	-2.52	Smooth	Truncate
1.75	3.50	.54	2.00	3.30	.002	-2.76	Smooth	Truncate
1.50	3.00	.48	1.80	3.26	.002	-2.78	Smooth	Truncate
				Modern *Quinoa negra*				
35.00	70.00	1.85	1.60	3.20	.044	-1.36	Reticulate	Rounded
47.00	94.00	1.97	1.60	3.20	.059	-1.23	Reticulate	Biconvex
51.00	102.00	2.01	1.50	3.18	.068	-1.17	Reticulate	Biconvex
39.00	78.00	1.89	1.50	3.18	.052	-1.28	Reticulate	Biconvex
48.00	96.00	1.98	1.50	3.18	.064	-1.19	Reticulate	Biconvex
45.00	90.00	1.95	1.50	3.18	.060	-1.22	Reticulate	Biconvex
45.00	90.00	1.95	1.50	3.18	.060	-1.22	Reticulate	Biconvex
22.00	44.00	1.64	1.40	3.15	.031	-1.50	Reticulate	Rounded
25.00	50.00	1.70	1.40	3.15	.036	-1.45	Reticulate	Biconvex
36.00	72.00	1.86	1.60	3.20	.045	-1.35	Reticulate	Biconvex
50.00	100.00	2.00	1.50	3.18	.067	-1.18	Reticulate	Biconvex
43.00	86.00	1.93	1.60	3.20	.054	-1.27	Reticulate	Biconvex
30.00	60.00	1.78	1.50	3.18	.040	-1.40	Reticulate	Biconvex
35.00	70.00	1.85	1.40	3.15	.050	-1.30	Reticulate	Biconvex
45.00	90.00	1.95	1.60	3.20	.056	-1.25	Reticulate	Biconvex
36.00	72.00	1.86	1.50	3.18	.048	-1.32	Reticulate	Biconvex

[a]Because the testa thickness is measured on only one side of the seed, we double the testa thickness value in order to account for the entire area represented by the testa when calculating the testa/diameter ratio.
[b]A natural log was applied to transform the values.
[c]Diameter originally measured in mm and then converted to microns before calculating the ratio. To calculate the ratio, we divide total testa thickness (microns) by diameter (microns).

Chiripa Chenopods: A Case Study

Chiripa is a well-known Formative period site in the south-central Andes (Bennett 1936; Browman 1978; Hastorf 1999a; Kidder 1956; Mohr-Chavéz 1988; Ponce Sanginés 1970; Portugal Ortiz 1992, 1998). The 7.7 ha site is within 1 km of the southern shore of Lake Wiñaymarka, the small southern portion of Lake Titicaca, in Bolivia (Figure 1). The Taraco Archaeological Project (TAP), directed by Dr. Christine Hastorf in association with the Unidad Nacional de Arqueología, is investigating the Early and Middle Formative occupation at Chiripa, 1500 B.C.–A.D. 100 (Bandy 2001; Hastorf 1999a). TAP has subdivided this occupation into three phases: Early Chiripa (1500–1000 B.C.), Middle Chiripa (1000–800 B.C.), and Late Chiripa (800 B.C.–A.D. 100), based on ceramic styles (Steadman 1999), architecture (Bandy 1999, 2001), and AMS dates (Whitehead 1999b; Table 2).

Whitehead (2000) notes that earlier researchers thought the Chiripa inhabitants to be full-scale agriculturalists based on the presence of sedentary villages or hamlets, an abundance of stone hoes, and recovery of possible tubers and chenopod grains. Starchy lumps, typically interpreted as tuber remains, appear throughout the site in low levels (Browman 1986; Erickson 1976; Towle 1961;

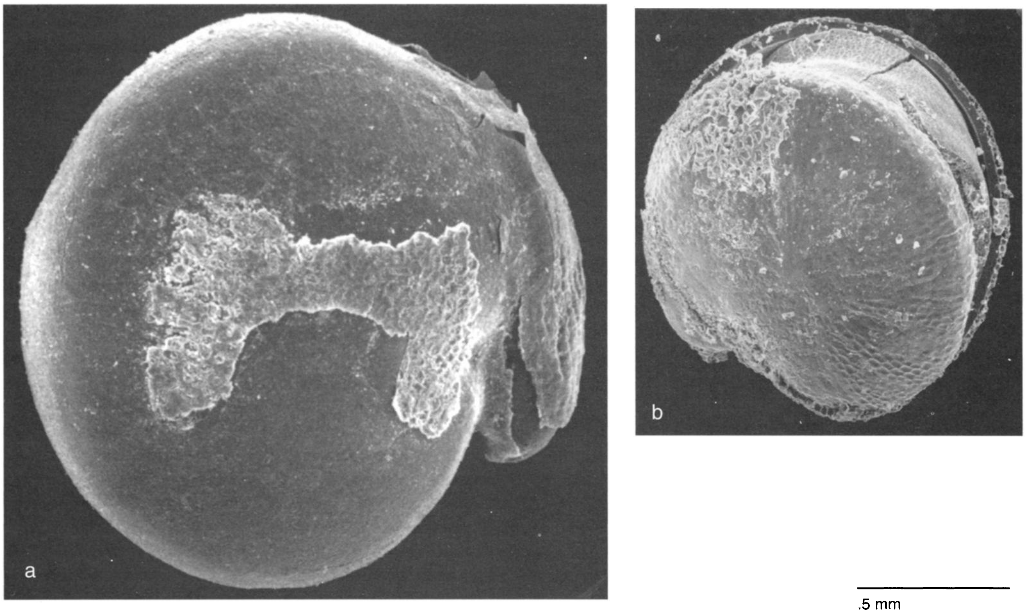

Figure 5. SEM Images of modern charred *Chenopodium* seeds: (a) quinoa and (b) *quinoa negra*. The quinoa has a smooth surface, while *quinoa negra* has a reticulate-aveolate (webbed-pitted) surface. The relative thinness of the quinoa testa is visible where it is flaking-off near the beak. Compare this to the relatively thick testa of the *quinoa negra* seed, visible around the perimeter where it is split open. Note the irregular patches of pericarp on both specimens, in the center of (a) and in the upper-left side of (b).

Whitehead 1999a, 2003). These have not been systematically studied, and methods for differentiating wild versus domestic tubers are not yet well developed. Whitehead's preliminary analyses of the Chiripa chenopods recovered by TAP shows that the seeds were, on average, much smaller in diameter (≤ .5 mm) than modern seeds (averaging 1.0 mm), and appeared undomesticated using standard light microscopy identification techniques. To determine whether the Chiripa inhabitants were cultivating domesticated plants or simply utilizing wild resources, we needed a more detailed analysis of the individual crops. The ubiquitous *Chenopodium* seeds provided the best opportunity.

Table 2. Formative Period Chronology (sensu Bandy 2001).

Regional Chronology	Chiripa Chronology	Dates
Late Formative II	Tiwanaku III	A.D. 300–500
Late Formative I	Tiwanaku I	250 B.C.–A.D. 300
Middle Formative	Late Chiripa	800 B.C.–A.D. 100
Early Formative II	Middle Chiripa	1000–800 B.C.
Early Formative I	Early Chiripa	1500–1000 B.C.

Selection of Chenopodium *Samples*

Whitehead analyzed flotation samples recovered during the 1992, 1996, and 1998 TAP excavations at Chiripa and isolated the identifiable *Chenopodium* seeds.[2] For the present study, we examined the separated chenopods (hereafter referred to as *Chenopodium* samples) from 10 of the analyzed flotation samples (hereafter referred to as flotation units, Table 3). We selected the 10 flotation units using three criteria: The first was secure temporal contexts. We selected three to four flotation units for each of the three Chiripa phases. Each had either an AMS date or an unmixed ceramic assemblage. The second was secure cultural contexts. Selected flotation units were drawn from primary cultural deposits. Archaeobotanical (Whitehead 1999a), faunal (Moore et al. 1999), and ceramic analyses (Steadman 1999) suggest the deposits derived from consumption activities, including cooking and disposal rather than plant processing (threshing, winnowing) or storage. The final criterion was good seed preservation. White-

Table 3. Contexts for the Archaeological *Chenopodium* Samples.

TAP Locus #	Original Chenopodium Seed Count	Area	Method of Dating Context	Context Description
		Early Chiripa		
845	183	Santiago/ Choquehuanca	CAMS # 325871 1507-1408 B.C.[a]	Charcoal lens
1315	1153	Santiago/ Choquehuanca	CAMS # 39167. 1371-1112 B.C	Dense occupation zone
1248	933	Santiago/ Choquehuanca	Early Chiripa Ceramics	Dense occupation zone
		Middle Chiripa		
1337	808	Llusco	CAMS # 38403 1047-834 B.C.	Low density midden
766	957	Santiago/ Choquehuanca	Middle Chiripa Ceramics	Pit ash fill associated with Choquehuanca court
745	510	Santiago/ Choquehuanca	Middle Chiripa Ceramics	Pit ash fill associated with Choquehuanca court
844	513	Santiago/ Choquehuanca	Middle Chiripa Ceramics	Pit ash fill associated with Choquehuanca court
		Late Chiripa		
1432	21,358	Montículo	CAMS # 37354 409-234 B.C.	Fill above floor in House 5
2033	481	Montículo	Ceramic Association	High density midden associated with House G
2036	865	Montículo	Ceramic Association	High density midden associated with House G

[a]AMS radiocarbon dates (calibrated 1 sigma error range) on *Chenopodium* seeds as reported in Whitehead 1999a.

head identified at least 400 *Chenopodium* seeds[3] from each of the selected flotation units.

Archaeological Contexts of the Chenopodium *Samples*

Early Chiripa. Chiripa began as a small village about 2 ha in area (Bandy 2001:107). No formal architecture has been found dating to the Early Chiripa period, but a few discrete activity areas have been excavated dating between 1500–1000 B.C. (Whitehead 1999b). The *Chenopodium* seeds representing this phase are from a dense occupational zone in the northwest sector of the site, here referred to as the Santiago/Choquehuanca area, and from a midden in the southwestern sector of the site, referred to as Llusco (Figure 2).

Middle Chiripa. During the Middle Chiripa phase (1000–800 B.C.), the population of the Taraco Peninsula grew, and the village of Chiripa increased to 4.25 ha (Bandy 2001:109). The TAP excavations encountered no domestic architecture, but found one of the earliest examples of corporate architecture in the Lake Titicaca Basin: a Choquehuanca semi-subterranean plaza/court, dating to 1000 B.C. (Hastorf et al. 1998). The structure is trapezoidal (14 by 13 m), and 2 m deep with a white-yellow clay floor and walls made of fieldstone plastered with yellow clay. The *Chenopodium* samples come from an ash-filled pit associated with the Choquehuanca sunken plaza/court, and a low-density midden, not associated with architecture, from the Llusco area (Figure 2).

Late Chiripa. From 800 B.C.–A.D. 100, the Chiripa settlement grew to 7.7 ha and the inhabitants constructed new, more elaborate corporate structures (Bandy 2001:134). Early in the Late Chiripa phase, the Choquehuanca structure was closed and another sunken enclosure, Llusco, was built in the southern portion of the site (Hastorf et al. 1998; Paz Soría 1999). Llusco was closed about 600 B.C., and construction of the site's most prominent feature, a 50-x-50-m platform mound called the Montículo, was begun (Bandy 2001; Browman 1978; Mohr-Chavéz 1988). The Montículo was built in two phases. From 600–400 B.C., the Chiripa residents built a series of rectangular "Lower Houses" (Kidder 1956), which were probably constructed around a small platform (Browman 1978). The

Table 4. Summary Data for Chiripa Archaeological *Chenopodium* Specimens Examined Under SEM.

Specimen Number	Testa thickness (microns)	Total Testa Thickness (microns)[b]	Log[a] Total Testa Thickness	Seed Diameter (mm)	Log Seed Diameter	Ratio Testa/ Diameter[c]	Log Ratio Testa/ Diameter	Texture	Margin configuration
				Early Chiripa					
132	14.50	29.00	1.46	1.10	3.04	.026	-1.58	Smooth	Truncate
133	7.50	15.00	1.18	1.10	3.04	.014	-1.87	Smooth	Indeterminate
135	15.00	30.00	1.48	.90	2.95	.033	-1.48	Smooth	Truncate
141	3.50	7.00	.85	1.00	3.00	.007	-2.15	Smooth	Indeterminate
143	9.50	19.00	1.28	1.20	3.08	.016	-1.80	Smooth	Truncate
146	17.50	35.00	1.54	.90	2.95	.039	-1.41	Smooth	Truncate
151	9.50	19.00	1.28	1.00	3.00	.019	-1.72	Smooth	Rounded
152	17.50	35.00	1.54	1.20	3.08	.029	-1.54	Smooth	Truncate
153	19.00	38.00	1.58	1.00	3.00	.038	-1.42	Smooth	Indeterminate
				Middle Chiripa					
161	14.50	29.00	1.46	1.40	3.15	.021	-1.68	Smooth	Indeterminate
162	20.00	40.00	1.60	1.20	3.08	.033	-1.48	Reticulate	Biconvex
165	18.00	36.00	1.56	1.30	3.11	.028	-1.56	Smooth	Truncate
176	32.50	65.00	1.81	1.20	3.08	.054	-1.27	Reticulate	Biconvex
182	14.50	29.00	1.46	.80	2.90	.036	-1.44	Canellate	Indeterminate
185	34.00	68.00	1.83	1.30	3.11	.052	-1.28	Reticulate	Biconvex
				Late Chiripa					
192	8.25	16.50	1.22	1.50	3.18	.011	-1.96	Smooth	Indeterminate
193	31.00	62.00	1.79	1.30	3.11	.048	-1.32	Reticulate	Biconvex
194	22.00	44.00	1.64	1.20	3.08	.037	-1.44	Smooth	Truncate
203	11.00	22.00	1.34	1.40	3.15	.016	-1.80	Smooth	Truncate
212	3.75	7.50	.88	1.20	3.08	.006	-2.20	Smooth	Indeterminate
213	16.00	32.00	1.51	1.60	3.20	.020	-1.70	Smooth	Truncate
214	11.00	22.00	1.34	1.30	3.11	.017	-1.77	Smooth	Rounded

[a]A natural log was applied to transform the values.

[b]Because testa thickness is measured on only one side of the seed, we double the testa thickness value in order to account for the entire area represented by the testa when calculating the testa/diameter ratio.

[c]Diameter originally measured in mm and then converted to microns before calculating the ratio. To calculate the ratio, we divide total testa thickness (microns) by diameter (microns).

inhabitants closed the Lower House level around 400 B.C. and began constructing the "Upper Houses," which were modified and used until around A.D. 100. The final monument included a semi-subterranean court and an open ring of permanent, surficial adobe and rock structures. The Montículo served as public ritual space where ancestors were revered and food was served, and possibly stored, for group events (Bandy 2001; Hastorf et al. 1998). The *Chenopodium* samples for this study come from a high-density midden that accumulated outside House G during its use, and fill associated with the closure of House 5 (Figure 2).

Analysis

The study of Chiripa *Chenopodium* seeds consisted of two stages: (1) detailed assessment of seed morphology via scanning electron microscopy, and (2) sorting of identifiable *Chenopodium* morphotypes via light microscopy.

SEM Analysis: Taxa Identification

For the SEM analysis, Bruno scanned each of the 10 selected *Chenopodium* samples from Chiripa and chose 22 seeds with intact testas: nine from Early Chiripa, six from Middle Chiripa, and seven from Late Chiripa (Table 4).[4] SEM analysis revealed two identifiable *Chenopodium* types at Chiripa: (1) seeds ($n = 17$) with thin (1–20 microns), smooth testas, and truncate to rounded margins, which are morphologically similar to modern quinoa (*C. quinoa*) (compare Figures 5a and 6a); and (2) seeds ($n = 4$) with thick (25–50 microns), reticulate testas and biconvex margins, which are

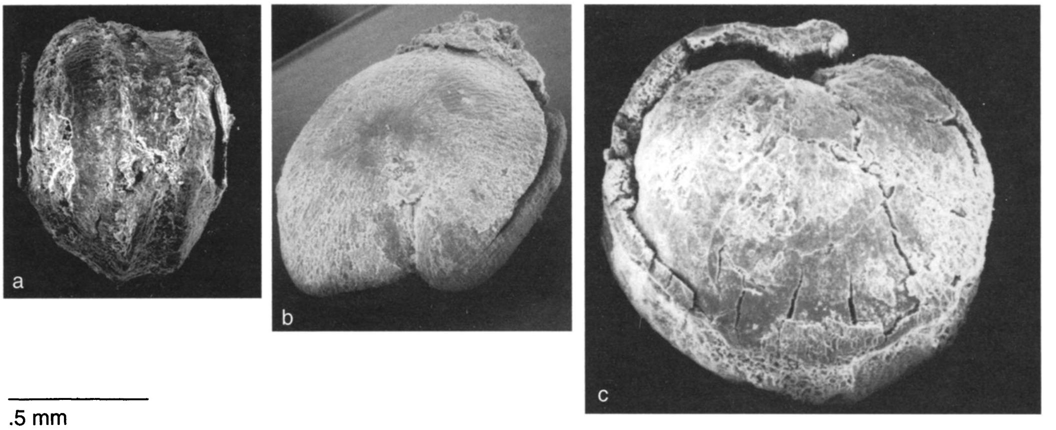

Figure 6. SEM Images of archaeological *Chenopodium* seeds: (a) quinoa; (b) *quinoa negra*; (c) no testa/truncate morphotype.

morphologically similar to modern *quinoa negra* (*C. quinoa* var. *melanospermum*) (compare Figures 5b and 6b).[5] These characteristics demonstrate that domesticated quinoa was present at Chiripa during the Formative period, as was its sympatric weed *quinoa negra*.

The small sample size precluded analysis of diachronic changes in quinoa morphology at Chiripa, such as increasing seed size or thinning testa (e.g., Fritz and Smith 1988; Gremillion 1993a). It was possible, however, to ascertain some general characteristics of the Formative period crop/weed complex by comparing the testa/diameter ratios of the archaeological and modern *Chenopodium* specimens (Figure 7). We applied two comparison tests (Least Significant Difference [LSD] and Bonferroni, SPSS 8.0) to assess the statistical significance of the differences in mean

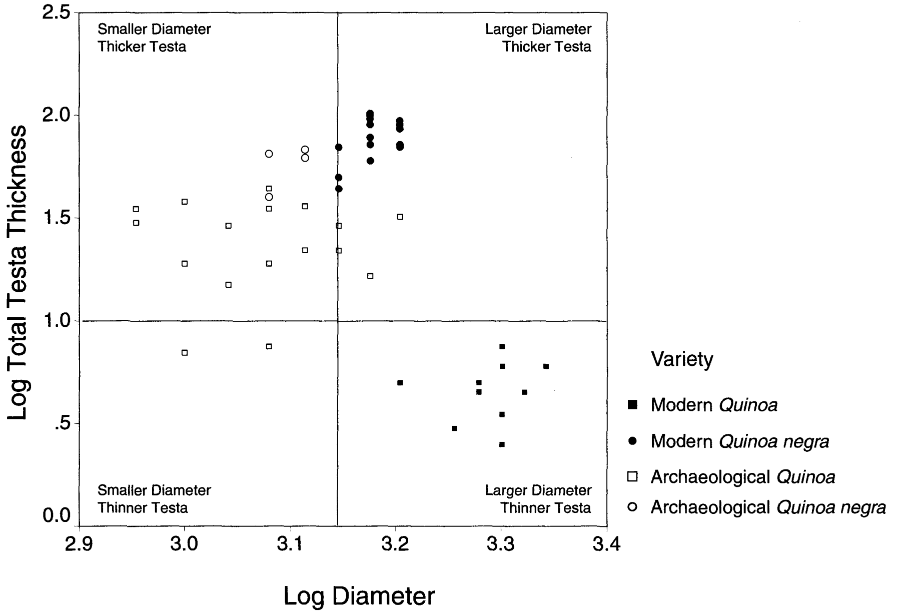

Figure 7. Scatterplot of log testa thickness and log diameter of archaeological and modern quinoa and *quinoa negra* seeds.

Table 5. Results of LSD and Bonferroni Multiple Comparisons Tests. Mean differences of the log testa/diameter ratios between modern and archaeological *Chenopodium* samples. Bold print indicates that the mean difference is significant at the .001 level.

	Modern Quinoa	Modern *Quinoa Negra*	Archaeological Quinoa
Modern Quinoa Negra	**1.3352**	—	—
Archaeological Quinoa	**.9178**	**.4174**	—
Archaeological Quinoa Negra	**1.2916**	.0435	**.3738**

testa/diameter ratios among the four populations: archaeological quinoa ($n = 17$), modern quinoa ($n = 11$), archaeological *quinoa negra* ($n = 4$), and modern *quinoa negra* ($n = 16$) (Table 5).

The modern crop and weed from the southern Lake Titicaca Basin differ markedly: modern quinoa seeds have large diameters and thin testas, while modern *quinoa negra* seeds have small diameters, and thick testas ($t = 1.3352$, $df = 26$, $p < .001$). In contrast, the archaeological quinoa and *quinoa negra* seeds are statistically different, but only slightly ($t = .3738$, $df = 20$, $p < .001$). They both have relatively small diameters and relatively thick testas.

The morphometrics of the two quinoa populations are also quite distinct ($t = .9178$, $df = 27$, $p < .001$). Archaeological quinoa seeds are not so large and their testas are not so thin as those of modern quinoa seeds; however, the archaeological quinoa do have thinner testas than either the modern or archaeological *quinoa negra* seeds. In contrast, the two populations of *quinoa negra* are quite similar morphometrically. These are the only two populations that have mean testa/diameter ratios that are not statistically different ($t = .0435$, $df = 19$, $p > .05$). Although modern *quinoa negra* is slightly larger in diameter than archaeological *quinoa negra*, both have relatively thick testas.

Sorting by Morphotype: Chenopodium *Representation by Phase*

After determining the morphological traits of archaeological quinoa and *quinoa negra* seeds under high magnification with the SEM, we found it possible to identify these attributes at lower magnification. Bruno returned to the remaining *Chenopodium* seeds in the 10 chosen flotation units (Table 3) and using light microscopy identified three morphotypes that we believe correspond to particular *Chenopodium* species.

Thin Morphotype-Quinoa (C. quinoa). These seeds have visibly thin testas (estimated to be < 20 microns), but also are distinguishable by their smooth seed coats and truncate margins (if not distorted by puffing). These seeds resemble the modern and archaeological quinoa seeds examined using the SEM (Figure 6a).

Thick Morphotype-Quinoa Negra (C. quinoa var. melanospermum). The thick (estimated to be > 20 microns), alveolate-reticulate testa of these seeds is easily visible with the light microscope. While most have biconvex margins, several are equatorially banded. This morphotype is similar to modern and archaeological examples of *quinoa negra* observed with the SEM (Figure 6b).

No Testa/Truncate Morphotype-Possibly Quinoa (C. quinoa). These specimens lack a seed coat, but have truncate perisperms. Although a few of these specimens may be *quinoa negra*, we argue that most are quinoa seeds because they have truncate perisperms and even minor pre- or post-depositional disturbance would have caused the thin testas to disarticulate. Note the two pieces of testa precariously remaining on the seed in Figure 6a and compare the remaining perisperm to that in Figure 6c. While the truncate shape of this morphotype is similar to that of *C. quinoa*, an absolute identification cannot be made without the testa. We include this morphotype in our analysis because it comprises up to 41 percent of the identifiable *Chenopodium* seeds from the samples.

Using these criteria, Bruno calculated the frequency of each morphotype per phase at Chiripa (Figure 8). Highly fragmented or distorted seeds were excluded; therefore, the final seed counts reflect the number of *Chenopodium* seeds that could be identified to morphotype in each phase.

The Early Chiripa phase samples ($n = 226$) yielded a few thin testa seeds (6 percent) but many thick testa seeds (35 percent) and many no

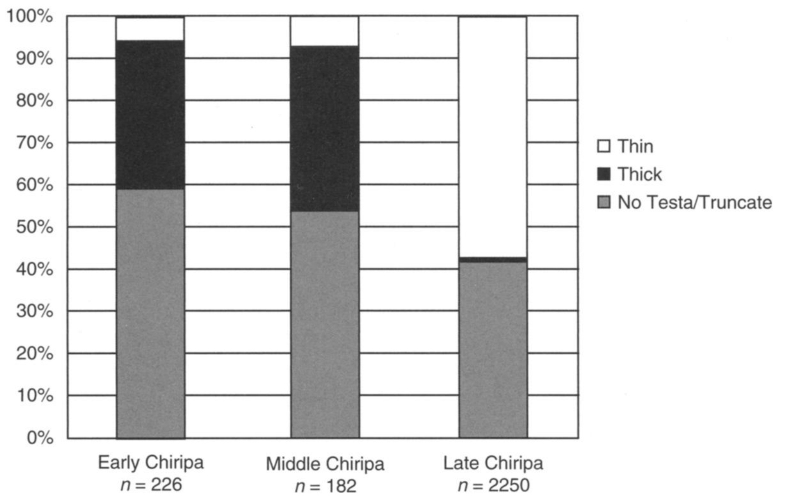

Figure 8. Frequency of *Chenopodium* morphotype per phase.

testa/truncate (59 percent) seeds. The proportions of thin, thick, and no testa/truncate morphotypes in the Middle Chiripa samples (*n* = 182 seeds) are similar to those of the Early Chiripa samples: 7 percent, 39 percent, and 54 percent, respectively. The morphotype frequencies of the Late Chiripa samples (*n* = 2,250 seeds) are distinct from those of the earlier phases. Fifty-eight percent are the thin morphotype and less than 1 percent are the thick morphotype. The no testa/truncate morphotype comprises 42 percent of the assemblage.

Discussion

Chenopod Morphology and the Chiripa Crop/Weed Complex

Testa thickness, surface texture, and margin configuration together show that the quinoa/*quinoa negra* crop/weed complex is present during the Formative period at Chiripa. An AMS radiocarbon date derived from five combined *Chenopodium* seeds larger than 1.2 mm from the Santiago/Choquehuanca area produced a date of 1507–1408 cal B.C. (Whitehead 1999b, TAP Locus #845, CAMS 25871) (Table 3). Because the date was obtained prior to this detailed identification of *Chenopodium* seeds, it is not possible to state the exact taxon/variety of the dated specimens. Given the presence of both domesticate and weed seeds in this sample, however, we posit that the quinoa/*quinoa negra* complex was present at Chiripa by about 1500 B.C. (3500 B.P.). This is the earliest direct date obtained on *Chenopodium* thus far in the Lake Titicaca Basin.

Examination of the morphometric features of the archaeological quinoa and *quinoa negra* seeds compared to their modern counterparts sheds light on several aspects of Formative period agriculture at Chiripa. Domestic quinoa is present at Chiripa, but its seeds are not so large or quickly germinating (thin testa) as those of modern quinoa. Morphometrically, modern quinoa/*quinoa negra* populations are very distinct, while Formative period quinoa/*quinoa negra* populations are quite similar. We suggest the relatively weak differences observed in Chiripa quinoa varieties represent an incipient stage of human selection that over time produced the sharp disparities seen in modern populations.

Archaeological quinoa from Chiripa had undergone only a few hundred years of human selection. In contrast, modern quinoa has experienced over 3500 years of selection, including modern agronomic manipulation to produce varieties with large, white seeds and low saponin content for local and international markets (Advisory Committee on Technology Innovation 1985; Risi and Galwey 1984; Tapia Vargas 1976; Wahli 1990; Ward 2000). Because the quinoa/*quinoa negra* complex was relatively young during the Formative period, the crop and weed forms were still closely related to their progenitor population and to each other, whereas the modern populations are removed by thousands of years.

Drastic morphometric differences seen in the modern quinoa/*quinoa negra* complex are not only a function of time, but also of success in keeping the two populations separate. Because *Chenopodium* is a wind-pollinated plant, some introgression always occurs between the weed and the crop (Nelson 1968; Wilson 1990). Management practices such as creating fields specifically for cultigens, weeding, and eliminating black seeds during the harvest and processing, so as not to plant them the next year, decrease the potential for crossbreeding. Therefore, similarities in testa/diameter ratios in the archaeological quinoa/*quinoa negra* complex may indicate that management practices of the Formative period Chiripa farmers permitted a higher degree of interbreeding than is seen today.

Morphotype Frequencies over Time: Tracking Chenopod Use and Management

The frequencies of quinoa crop and weed seeds in the Chiripa samples provide additional insight into Formative period *Chenopodium* cultivation. Given that the crop and the weed grow in the same habitat, cross-pollination often produces a few black seeds on the quinoa plants (Wilson 1990:99). Thus, the presence or absence of *quinoa negra* seeds in the archaeological *Chenopodium* samples indicates the degree to which humans removed the black seeds during harvest and processing. Because the samples represent chenopods chosen during production, their composition also reflects which seeds people considered most acceptable as food.

Early and Middle Chiripa (Early Formative) samples contain a mixture of quinoa and *quinoa negra* seeds. This suggests that the people living at Chiripa during this time did not completely separate the crop from the weed in production, creating meals from a combination of domestic and weed chenopod grains. In terms of production, this mixture suggests that the cultivated quinoa plants of the Early Formative had more black seeds than do modern plants, and/or that the cultivators allowed *quinoa negra* plants to grow alongside domesticates and harvested both varieties. Perhaps these early farmers did not "weed" as modern ones do, pulling up the *quinoa negra* plants as soon as they are visible (as observed by Whitehead in 2001; Wilson 1988b, 1990). It is also possible that early farmers did not construct formal fields, but rather maintained home gardens containing both quinoa and *quinoa negra* plants. This hypothesis is supported by Bandy's (personal communication 2002) analysis of lithic materials from the TAP excavations at Chiripa; Early Chiripa contexts had no stone digging implements, and Middle Chiripa contexts had only one stone hoe fragment.

As the elevated, multiroomed Montículo signals new developments in social, ritual, and political life during Late Chiripa (Middle Formative), approximately 800 B.C., new patterns in *Chenopodium* seed frequencies indicate changes in food preferences and innovation in agricultural practices. Of 2,250 identifiable *Chenopodium* seeds examined from the Montículo, only 15 were identifiable as *quinoa negra*, strongly suggesting that people at the Late Chiripa village did not consider black seeds an appropriate food item in the Montículo context.

The paucity of *quinoa negra* seeds also suggests that the people at Chiripa became more meticulous cultivators during the Middle Formative period. They may have accomplished this by weeding the *quinoa negra* plants as they grew, exclusively harvesting the quinoa plants, selecting only quinoa seeds for planting, and/or creating formal fields for the crop. The hypothesis that quinoa cultivation intensified through the creation of formal fields is supported by Bandy's lithic analysis, in which he estimates that over 380,000 basalt hoes may have been in use on the Taraco Peninsula during the Middle Formative period (Bandy 2001:181).

Conclusion

This study of *Chenopodium* seeds from the site of Chiripa, Bolivia, illuminates several small-scale processes involved in Formative period agriculture on the Taraco Peninsula, complementing previous studies of settlement, landscape modification, and stone tool use. These data provide direct evidence for the presence of the quinoa/*quinoa negra* crop/weed complex in the Chiripa agricultural system by 1500 B.C. Although the archaeological quinoa and *quinoa negra* seeds have distinct morphologies, their testa thicknesses and seed sizes are more similar than those of their modern counterparts, which are the products of thousands of years of human selection and management.

Based on patterns in *Chenopodium* morphology and frequencies, we suggest that Early Formative (Early and Middle Chiripa) agricultural production at Chiripa was characterized by small-scale gardening where both quinoa and *quinoa negra* were grown and harvested. Additionally, this mixture of domestic and weed seeds appears to have been acceptable food, as evidenced in remains from domestic middens and in samples associated with the early corporate architecture of Choquehuanca.

Around 800 B.C., we find a drastic decrease in the frequency of *quinoa negra* seeds compared to quinoa seeds, signaling changes in crop management and use. In order to reduce the number of *quinoa negra* seeds in the yearly harvest, farmers may have begun creating formal fields for the crop, weeding, and practicing more careful seed selection. This shift in agricultural production coincides with the development of new ritual and political practices at Chiripa. The presence of large quantities of quinoa seeds at the Montículo suggests that this food played an important role in the activities at this location.

Future studies of *Chenopodium*, with larger sample sizes and greater spatial and temporal representation, promise to reveal much more about the evolution of quinoa domestication and productive intensification in the Lake Titicaca Basin, and elsewhere in the Andes. Such studies can help delimit the trajectory of agricultural intensification in the region and its relationship to concomitant developments in sociopolitical complexity.

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Notes

1. Bruno conducted a morphometric study of chenopods growing in the southern Lake Titicaca Basin, including *C. quinoa*, *C. quinoa* var. *melanospermum*, *C. pallidicaule*, and *C. ambrosioides*. Aymara farmers in the communities of Chiripa and Achuta Grande, Bolivia, kindly gave the authors portions of their harvests. One to two seeds from each sample were examined with SEM. Further details of the comparative collection and the morphological analysis can be found in Bruno (2001, 2003). Seeds chosen for SEM analysis represent the average seed shape and size from each taxon or archaeological sample. Financial constraints limited SEM analysis to an average of ten seeds from each unit (modern comparative taxon or archaeological flotation unit). This sample size was deemed appropriate for verifying the range of testa thickness in the modern and archaeological samples. The results are consistent with other morphological studies with larger sample sizes (e.g., Eisentraut 1998; Fritz and Smith 1988; Gremillion 1993a, 1993b; Nordstrom 1990; Smith 1984, 1985a).

2. Charred botanical remains were recovered from excavated sediments by flotation with a modified SMAP machine (Hastorf 1999b). All flotation samples were sorted and identified by Whitehead at the University of California, Berkeley, Paleoethnobotany Laboratory.

3. One sample (TAP Locus #845) has fewer than 400 seeds, but was included because it produced the oldest date for the site.

4. Because identification of domesticated chenopods was a primary objective of the project, more seeds with relatively thin testas were selected for the SEM analysis. Bruno conducted the SEM analysis with a Hitachi S-450 microscope in the Biology Department at Washington University under the supervision of microscopy technician, Michael Veith. Prior to the SEM analysis, each seed was examined under a Wild M3 dissecting microscope in the Washington University Paleoethnobotany Laboratory to record seed diameter. During the SEM analysis, each seed was viewed on screen at a magnification of approximately 650X to determine the best location for measuring the testa, and to record descriptions of seed coat texture and margin configuration. Micrographs of the testa were taken at magnifications of 1000X to 4000X. Because the SEM does not have on-screen measuring capabilities, testa measurements were made from the micrographs. Testa thickness was measured in millimeters with a ruler and mathematically converted to microns. Statistical analyses were performed using SPSS 8.0.

5. One archaeological specimen (#18237) has a canellate seed coat texture, a thin testa (14.5 microns), and a relatively large diameter (1.2 mm). This specimen falls within the range of modern *C. pallidicaule* (Bruno 2003), but we refrain from designating it as such because it is only one specimen and we excluded it from the following analyses.

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