Origins of Food Production in the High Andes

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https://doi.org/10.1093/acrefore/9780190854584.013.442
Published online: 29 October 2021

Summary

Vertical topography, high altitude, infertile soils, and an arid climate make the Andes of South America a difficult region for agriculture. Nonetheless, archaeologists have found that potatoes, oca, quinoa, and kañawa were first domesticated by ancient famers in and near a region known as the Altiplano. Research indicates that approximately 6,000 years ago hunter-gatherers began to cultivate wild ancestors of these crops. Shortler thereafter, llama and alpaca herders played an important role in developing crop cultivation strategies; potatoes were uniquely adapted to a mobile pastoral lifestyle. By about 1,500 BCE there is archaeological evidence that these crops were fully domesticated and supported early village life. Eventually tubers and chenopods were foundational sustenance for civilization and cities across the pre-Hispanic Andean highlands. Breeding over the last four millennia by generations of Indigenous Andean farmers in the diverse environments and climatic conditions of the Andes has resulted in a hugely diverse array of these crops. The outcome of these efforts is that hundreds of varieties of quinoa and over 5,000 varieties of potatoes are grown by Andean farmers in the 21st century. Potatoes in particular are a unique case of domestication for two reasons: (a) ancient farmers figured out how to store them long term through a freeze-drying process; (b) chemicals that are toxic to humans were not bred out of all varieties; rather, ancient people figured out that eating particular clays made the toxic potatoes less bitter and edible. Through paleoethnobotanical and genetic research, archaeologists have begun to shed light on the tangled history of Andean peoples and their crops.

Keywords: domestication, farming, potatoes, quinoa, tubers, Andes, Altiplano

Subjects: Archaeology

Introduction

The extremely vertical topography of the highland Andes mountains simultaneously facilitated and constrained the development of agriculture in the region (fig. 1). On the one hand, farmers were able to take advantage of unique and proximate microenvironments located at different elevations to breed thousands of landraces of tubers and grains adapted to particulars locales. On the other hand, the steeply graded mountain slopes, high elevation creating hypoxic conditions, and rocky infertile hillsides limited what crops farmers could grow. While research is still hazy on precisely when, sometime between 10,000 and 6,000 years ago Archaic period hunter-gatherers familiar with the landscape began to cultivate and experiment with breeding plants in the highland Andes (fig. 2). The two most famous of these crops are potatoes and quinoa.

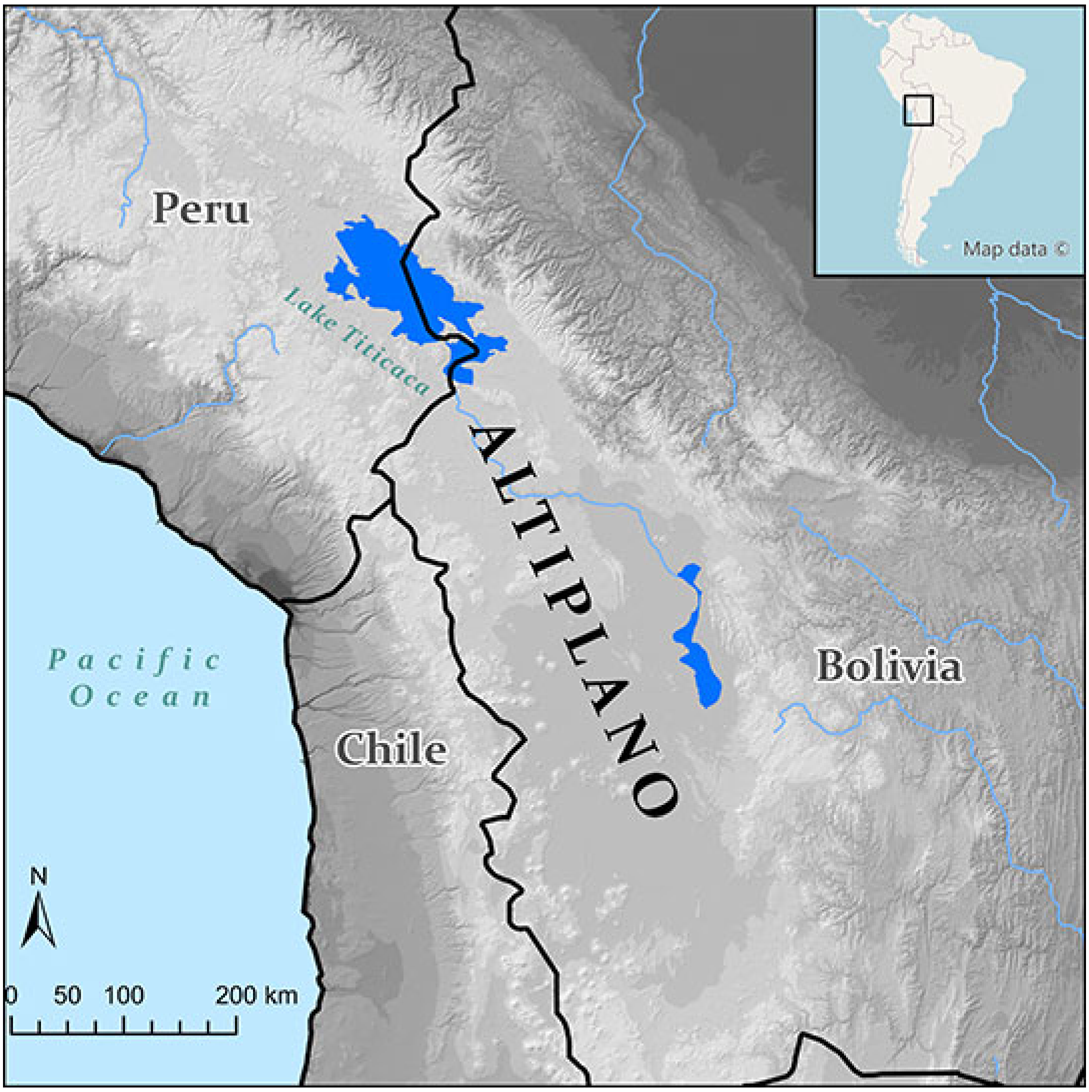

Figure 1. A map of the Altiplano.

Source. Map rendered by D. W. Mixter.

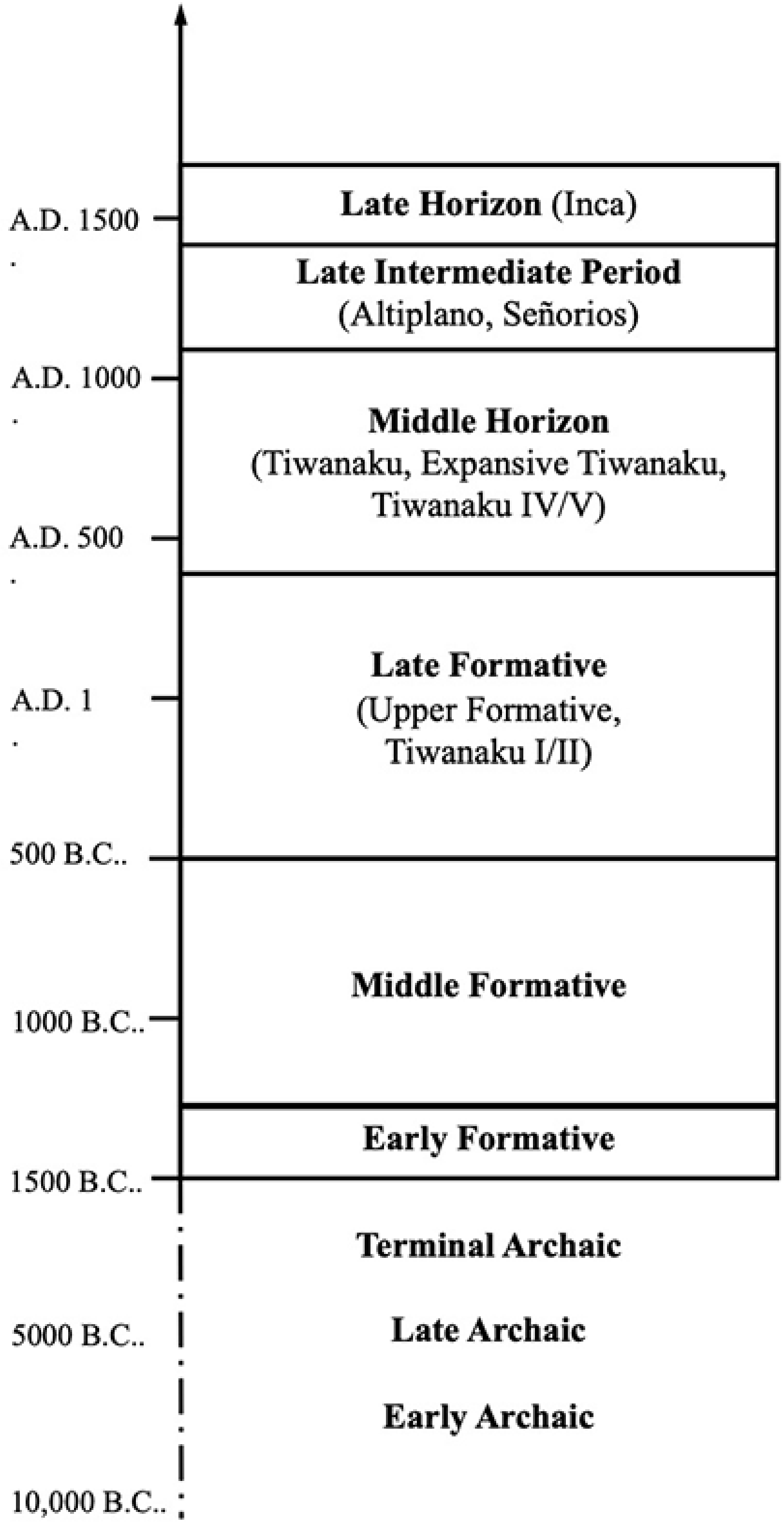

Figure 2. Chronology of the Altiplano including time periods mentioned.

Source. Author.

Domestication in the Altiplano

Based on the modern range of the wild ancestors of crops, the region known as the Altiplano at an elevation of 3,750 masl (12,000 feet) has been suggested as a center of domestication where quinoa, potatoes, and oca were first cultivated. As such, the focus here is on research that has been carried out in the Altiplano, as well as work that complements these findings. In this region, plant breeding by generations of ancient farmers made crops more congenial for humans; in other words, plants became better suited for food production and consumption. Domestication and breeding programs resulted in measurable changes in the gross morphology and genetics of the tubers potatoes, oca, and chenopod grains including quinoa kañawa crops. In pre-Hispanic times, the successful breeding programs, nutritional value, and tastiness of these crops led to their diffusion, with them ultimately being cultivated across the far reaches of the South American continent. They were grown by Indigenous farmers throughout the highlands of western Venezuela in the north, all the way to southern Chile. Early cultivation of grains and tubers marked the beginning of the process of coevolution between humans and plants that resulted in a highly resilient agricultural system that has made possible human settlements and civilization in the region ever since. It must be noted that domestication of crops occurred across the Andean highlands, as well as in the adjacent regions including the South American Pacific coast and the Amazonian rainforest (Piperno 2011, S455). The focus here is on the Altiplano simply because it seems to have been a locus of domestication of two major classes of crops based on genetic and paleoethnobotanical research. In this article, I discuss what we know about the when and the where of tuber and chenopod domestication in the Altiplano and models of domestication that underpinned these processes.

Broadly speaking, identifying the where and when of crop domestication sheds light on the intertwined histories of humans and their natural environments. As plant biologists and geneticists have found, regions where domestication took place are still locations that have high diversity of landraces grown by Indigenous farmers today (Curti et al. 2012; Vavilov 1926). As we seek solutions to future food insecurity due to growing human populations and anthropogenic climate change, this crop diversity may provide new and novel sources of genetic material. Furthermore, diversity in crop appearance, texture, taste, and nutritional profile has been sought out by agronomists, chefs, and consumers throughout the world today. High elevation and arid regions, including the Altiplano, are particularly threatened by climate change that will inevitably lead to loss of biodiversity (Howden et al. 2007; Randin et al. 2009; Rosengrant 2011). Since the crops of the Altiplano are already adapted to salty soils, extreme annual swings in precipitation and climate, as well as the high-altitude and arid ecology of the region, Andean tubers and chenopods in particular may provide solutions to food security going forward. With this in mind, it's not just archaeologists who are interested in the origins of agriculture; agronomists focused on food security, climate change researchers, chefs, and consumers looking to diversify their menus, and Indigenous people looking to preserve and reclaim their agronomic and culinary traditions, all have a stake in understanding the origins of agriculture in the Andean Altiplano.

Tubers

Approximately sixteen species of tubers were domesticated in the highland Andes (Flores et al. 2003) (fig. 3). Though compared to other major food crops of the world, very little archaeological research has focused on identifying the origins of Andean tuber cultivation. This lack of research is in part due to preservation issues with which archaeologists all over the world deal. As water-engorged plant tissues, tubers do not preserve as readily as other artifact types like lithics, bone, or ceramic sherds. In addition, the way in which tubers are prepared and consumed leads to further preservation issues. Potatoes and other Andean tubers are boiled and mashed in preparation for the dinner plate, and as a result, they are rarely dropped into fires as compared to grains or roasted meat. The dense water content of tubers means that when they are roasted or accidentally dropped in a fire, they do not carbonize wholly like grains (Pearsall 2015, 131) (fig. 4). When archaeologists find charred bits of burned tuber, they are difficult to identify to family or species, so they are called parenchyma, which means plant storage tissue. Counts of parenchyma lend insight into tuber cultivation and consumption but identifying where and when these plants were domesticated based on morphological changes in the structures of plants, as paleoethnobotanists do with grains, is nearly impossible. As a result, most of what is known about the timing and geography of tuber domestication derives from indirect archaeological evidence correlated with crop processing and cultivation, and from genetic data and ethnographic analogies.

Figure 3. An array of native tubers for sale in a 21st-century Altiplano market.

Source. Photo by author.

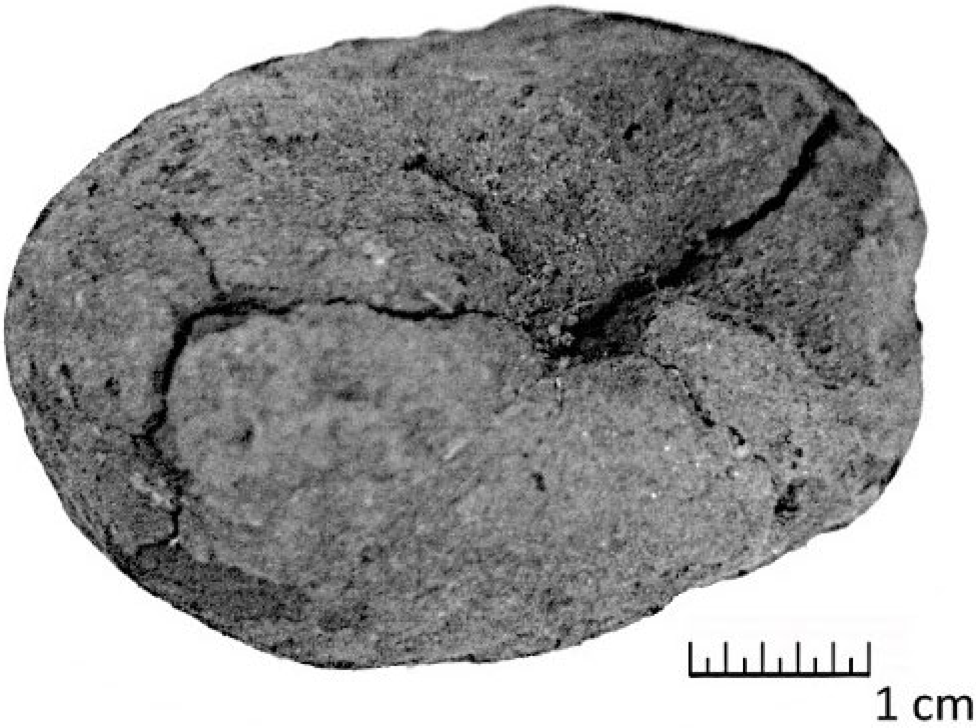

Figure 4. Image of a carbonized archaeological potato, probably a freeze-dried potato called chuño, recovered from an archaeological site in the Altiplano.

Source. Photo by author.

For example, some of the earliest evidence of tuber use in the region where potatoes and oca were domesticated is found in wear patterns on human teeth. Eleven individual crania excavated from the Archaic period site Soro Mik'aya Patjxa, exhibited tooth wear on their upper incisors and canines known as lingual surface attrition of the maxillary anterior teeth (LSAMAT) (Watson and Haas 2017). This site is a 7,000-year-old hunter-gatherer encampment in the Altiplano located west of Lake Titicaca. LSAMAT is a condition that has been ethnographically correlated with processing tubers, such as peeling, sucking, and chewing. While these findings do no indicate cultivation, or breeding, they do suggest intensive use of wild progenitor tubers prior to farming, an important first step in the domestication process. It still remains unclear what type of tubers these early hunter-gatherers were eating. Hopefully future research will shed light on the subject.

Potatoes

Potatoes (*Solanum tuberosum*) are one of the most important tuber crops around the world today, taking center stage in variety of cuisines ranging from fries to pancakes, to chips, soups, curries, and stews. In the highland Andes, Indigenous people still grow over 5,000 potato landraces adapted to different elevations, climates, photoperiods, and drought, disease, and pest tolerances (Brush 1980; Brush et al. 1995; De Haan et al. 2006). In comparison to their wild relatives, these landraces are on average larger, more colorful, and contain lower levels of toxic chemicals that help the wild plant fend of insects and other pests. Since pre-Hispanic times, these landraces have been cultivated throughout the mountains of western Venezuela, Colombia, Ecuador, Peru, Bolivia, Argentina, and all the way to southern Chile. Based on genetic research, potatoes were selected from a single landrace of the species *Solanum brevicaule* that grows today in the highlands of southern Peru near Lake Titicaca; from this location cultivation of potatoes diffused throughout the Andes (Spooner et al. 2005).

The earliest direct evidence of potato processing for culinary purposes in the Altiplano is from microbotanical remains recovered from ground stone tools. Archaeologists unearthed an open-air village known as Jiskairumoko, dating to the Late Archaic to Early Formative period transition, on the western shores of Lake Titicaca in southern Peru (Rumold and Aldenderfer 2016). The Late Archaic to Early Formative period spans the onset of sedentism and early food production in the Altiplano (Craig 2005; Hastorf 2008; Stanish 2003). Ground stone tools from all levels of occupation at Jiskairumoko revealed evidence of starch grains from the *Solanum* genus, though researchers were unable to determine if these microbotanicals were from wild, cultivated, or domesticated species (Rumold and Aldenderfer 2016). Importantly, these findings mark intense tuber processing, exactly what archaeologists would expect to find during the time period when people were transitioning from a hunter-gatherer existence to a lifestyle committed to agriculture.

It has been argued that the origins of civilization were only possible due to the domestication of grains, downplaying the role of tubers since they cannot be stored for long periods of time (Scott 2017). Andean tubers are an exception due to the fact that ancient farmers figured out how to dehydrate potatoes in a simple freeze-drying process, making them storable for upwards of five years (D'Altroy 2002). Colloquially referred to as *chuño*, freeze-dried potatoes are still a staple of Altiplano cuisine. To make chuño, Andean people lay potatoes out in the sweltering midday neotropical sun, they step on the potatoes to bleed the water out of them with the weight of their feet, and finally, nighttime frosts complete the freeze-drying process (Hastorf 2017b, 96) (fig. 5). Starch grains that resemble chuño were identified on ground stone tools from the Late Archaic–Early Formative site, Jiskairumoko (Rumold 2011, 295). Without the water content of typical tubers, chuño burns and is preserved the same way as grains. Burnt parenchyma remains found in archaeological samples, including the Formative period sites Chiripa and Kala Uyuni located south of Lake Titicaca, and three Formative period Wankarani sites located in the Central Altiplano, have been attributed to burnt freeze-dried potato (Bruno 2014; Langlie and Capriles 2021; Whitehead 2006). Additionally, caches of chuño (and quinoa) were found in ceremonial structures at the Formative period site of Chiripa (Hastorf 2017a; Hastorf et al. 2008). The abundance and high ubiquity of these remains in Late Archaic and Formative period sites indicate chuño-making techniques were developed and perfected by the time that people first settled in villages in the highland Andes. The location of these remains in ceremonial structures indicates that freeze-dried potatoes and quinoa were revered crops included in rituals. Today, chuño is appreciated reconstituted and in hearty soups and stews, and boiled, roasted, mashed, and fried potatoes are enjoyed by Indigenous Andean groups as well as people all over the word.

Figure 5. Stomping water out of potatoes in the sweltering Altiplano sun to make freeze-dried potatoes called chuño.

Source. Photo by author.

Oca

Oca (*Oxalis tuberosum*) is a sweet-tasting cylindrical stem tuber ranging in color from white, red, yellow, pink, purple, to black (Flores et al. 2003) (fig. 6). While not well known outside of the Andes, oca is sweeter than potatoes, and a delectable and nutritious crop high in carbohydrates, calcium, fats, and fiber (Flores et al. 2003, 162). Genetic research on crop and wild relatives still growing in the Andes today indicates a single origin for oca domestication, spanning the region from southern Peru to northwestern Bolivia. Based on this research, the Altiplano is thought to be the location where oca was domesticated.

Like potatoes, oca can be freeze-dried and stored for years (Hastorf 2017b, 96). Known as *cana*, no archaeological evidence of oca has been identified in the Altiplano (Emshwiller and Doyle 2002), though it is possible and likely that some of the parenchymatous tuber tissue identified in paleoethnobotanical samples from the Altiplano derives from freeze-dried oca. Charred seeds identified to the genus *Oxalis* have also been found in archaeological deposits from Formative period contexts on the southern shores of Lake Titicaca (Bruno 2014), though these seeds are not necessarily evidence of cultivation. Modern oca does not produce seeds, rather it is vegetatively propagated (Flores et al. 2003, 161). The archeological *Oxalis* sp. seeds may be the result of foraging camelids who consumed wild *Oxalis* spp. while humans used the llama dung to fuel fires, as is common in the region (Bruno and Hastorf 2016; Hastorf and Wright 1998). Hopefully, further research will shed light on oca cultivation, selection, and storage techniques.

Figure 6. Oca pictured in the foreground for sale in a 21st-century Altiplano market. An array of potatoes is for sale in the background.

Source. Photo by author.

Chenopods

Two species of chenopods are grown commercially as crops in the Andes today: the well-known health food grain quinoa (*Chenopodium quinoa*) and its lesser-known more drought-tolerant relative kañawa (*Chenopodium pallidicaule*). It has been suggested that the Altiplano is home to the domestication of these crops. Much paleoethnobotanical research has shown that it was grown prehistorically throughout Peru, Chile, and Argentina (Planella et al. 2015) (figs. 7 and 8). Through genetic research it has been determined that quinoa's closest wild relative is likely the species *Chenopodium hircinum* (Jarvis et al. 2017). *Chenopodium hircinum* and quinoa's crop companion weed that is the same species but morphologically distinct are both colloquially known as *quinoa negra* or *ajara* (Bruno 2006, 32). As a weed, quinoa negra thrives in disturbed soils, ditches, and fence rows alongside stands of quinoa. While not intentionally cultivated by humans, quinoa negra is still edible. Quinoa is a particularly nutritious grain with a high protein to carbohydrate ratio and has all the essential amino acids that humans need (Repo-Carrasco et al. 2003; Vega-Gálvez et al. 2010). The papery pericarp containing high levels of saponins that give humans gastrointestinal discomfort are manually removed through stomping and winnowing, grains are then washed. Quinoa and kañawa boiled and eaten in soups or stews, parched and ground into flour, or made into an alcoholic beverage called chicha. The tender immature leaves of chenopod plants, whether wild, weedy, or domesticated, are regularly consumed by people and have a spicy taste, similar to arugula.

Figure 7. A cached of carbonized ancient quinoa recovered from an archaeological site in the Altiplano.

Source. Photo by author.

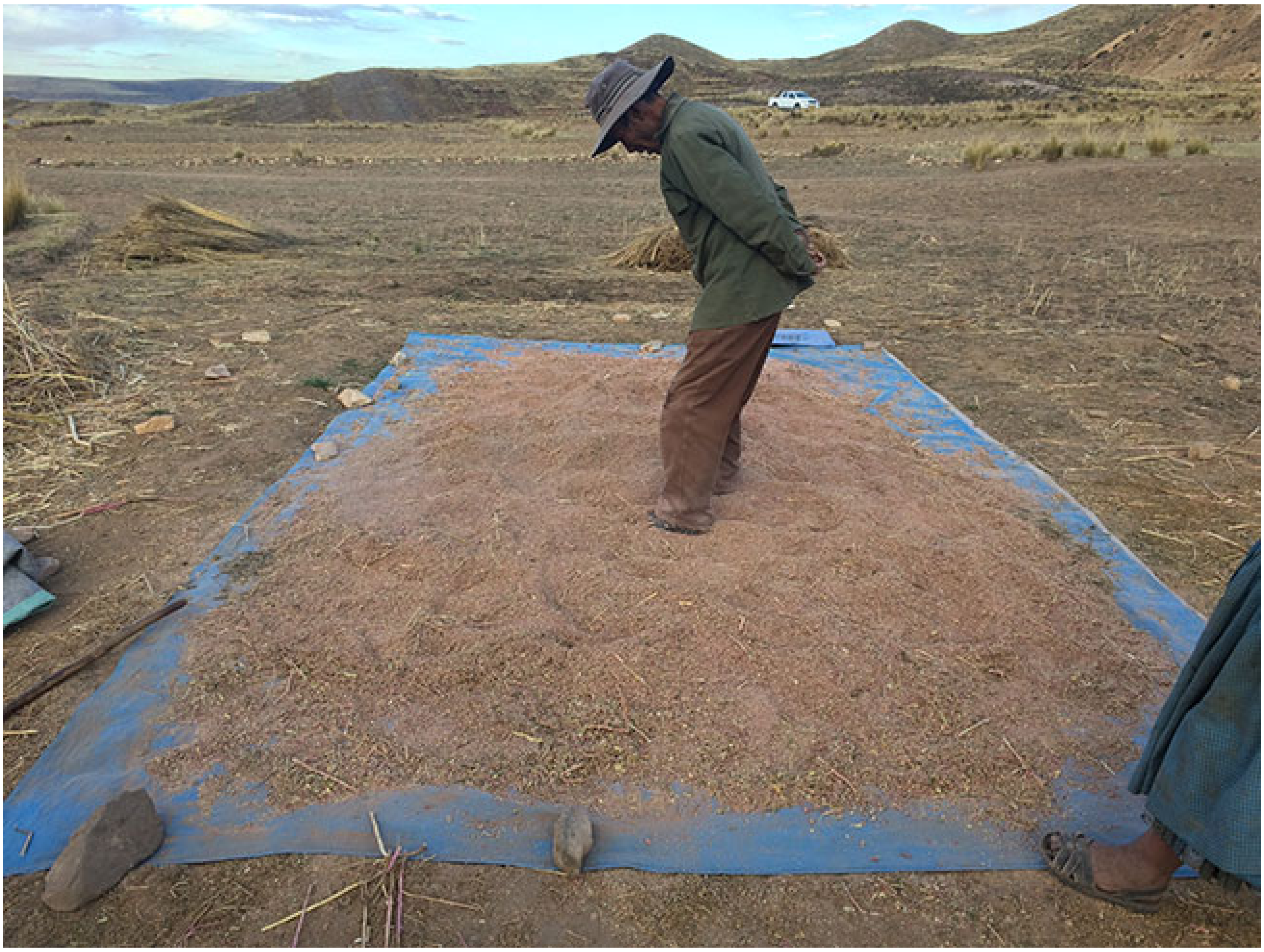

Figure 8. Threshing quinoa, or, in other words, removing the pericarp and chaff from the seed by stomping on it.

Source. Photo by author.

Much archaeological research focused in the Altiplano has begun to shed light on the timing and location of domestication of quinoa and kañawa. The success of this research is in part because chenopods grains are abundant in archaeological contexts. Their small size, the way they are processed (parching), and the way they are cooked, leads to regular incidences of these grains being charred in cooking fires. These small, charred grains preserve well in the archaeological record. As a result, paleoethnobotanists have not just identified when and where ancient Andean people consumed this grain, they have also identified evidence of morphological changes in ancient chenopods associated with crop breeding and domestication over time. This, coupled with genetic research, provides us with a much clearer historical understanding of quinoa domestication in the Altiplano, as compared to tubers.

Quinoa and kañawa are well adapted to the inter-annual variation in the climate and the harsh ecology that characterizes the highland Andes. Both are tolerant of salty soils, grow well at high altitudes and with little precipitation, though kañawa is more drought and salt tolerant. Today, farmers across the Andes cultivate hundreds of varieties of quinoa (Andrews 2017), each adapted to different and particular ecological conditions (Winkel et al. 2015). Research indicates local quinoa varieties from the southern Altiplano fail when planted in the moister environmental conditions around Lake Titicaca (Danielsen et al. 2003) and varieties grown further north around

Lake Titicaca struggle to grow in the drier and colder conditions in the southern Altiplano (Winkel et al. 2015). The array of varieties grown in the Altiplano today speaks to long-term breeding regimes of chenopods by farmers across the region stretching back into antiquity.

Experimental archaeological research has shed light on ancient processing of quinoa (López 2012; López et al. 2012; Petrucci and López 2020). Scholars have looked at how farmers thresh, stomp, winnow, parch, grind, and store quinoa, and how these processing techniques alter the morphology of quinoa grains. As each processing technique alters grains in distinct ways, researchers have been able to identify evidence of these post-harvesting treatments in archaeological samples. These treatments of quinoa are not only important for removing saponins that sicken humans, thereby making the grains more suitable for consumption, they also speak to transforming quinoa into particular culinary products. This type of detailed and promising research has the potential to bring to life the intertwined life histories of humans and their crops in the past.

Genetic research has revealed a few insights into the domestication of quinoa. For example, four genetic groups associated with different geographic zones have been identified in Argentina successions, including Altiplano, Dry Valleys, Eastern Humid Valleys, and Transition area (Curti et al. 2012). This same study concluded that varieties from the highlands seem to be more "advanced in terms of domestication" whereas varieties from the valleys show narrower genetic variability, pointing to diffusion into the region, probably from the highland Altiplano region (Curti et al. 2012, 123). Building on this work, geneticists have sequenced the whole genome of quinoa (Jarvis et al. 2017). The focus of this study was on identifying key traits in the crop so they could improve its commercial value and increase the world's future food security. This research also has implications for understanding the ancient history of quinoa. This team found a DNA sequence that produces sweet quinoa varieties with lower levels of saponins that upset human stomachs and destroy red blood cells. These varieties are not widely grown in the Andes today. Rather, chenopod relatives with higher levels of saponins are more common because saponins protect the plant from nonhuman predation (Paterson and Kolata 2017). This indicates that farmers have prioritized breeding quinoa varieties that are resistant to predation over ones that are less delectable and poisonous. More importantly for archaeologists, this research raises two possibilities for the origins of domestication: (a) quinoa was domesticated in the highlands of the Andes and diffusion led to the cultivation of an independent population on the coast; or (b) there were separate domestication events in the highlands and on the coast (Jarvis et al. 2017, 16). This is a promising hypothesis that may be resolved by ancient genetic research and macrobotanical research in the future.

From archaeological research, it is estimated that approximately five and a half millennia ago the wild relatives of quinoa and kañawa were domesticated in the Altiplano region (Bruno 2006; Planella et al. 2015; Pearsall 1992). While some scholars have argued that quinoa domestication occurred earlier, evidence is still scant. For example, based on the presence of a single charred chenopod grain found on the coast of Peru outside the range where wild relatives grow, researchers have argued domestication of quinoa occurred before *c.*5500 BCE (Dillehay et al. 2007); however, Accelerator Mass Spectrometry (AMS) analysis of that seed returned a modern date (Rosen et al. 1996). While the researchers argue for AMS dating issues, it is also possible the seed was simply an intrusion, as annual seeds are designed to burrow into the ground for reproductive reasons, making it wholly possible this is what happened. Future research may shed more light on this issue.

Large quantities of chenopod seeds were found in Late Archaic hunter-gatherer sites on the western shores of Lake Titicaca, indicating human groups were collecting wild resources if not cultivating plants by this time period (Eisentraut 1998). Along these same lines, Browman (1989) documented diachronic increases in seed size at the Formative period site of Chiripa located on the southern shores of Lake Titicaca. Specifically, he found that from *c.*1350–1000 BCE all chenopod seeds are about the same size, and the mean diameter of seeds increased from all strata after 1000 BCE. An increased in seed diameter is associated with seed bed competition, where larger seeds outcompete the smaller ones in fields prepared by farmers for the cultivation of crops (De Wet and Harlan 1975). Farmers may have also selected larger seeds because they have better culinary properties and contain less bitter-tasting saponins (Browman 1989). Browman also notes that he found a bimodal distribution of seed diameter sizes from these later strata. While he did not draw this conclusion, based on what archaeologists in the 21st century have learned about differences in seed diameter between quinoa and kañawa, the identification of a bimodal distribution of seeds may indicate farmers at Chiripa were cultivating both quinoa and kañawa. While this research was excellent in precision and quality, no seeds were directly dated, and key morphological analyses that confirm species identification had yet to be developed. This is important to note because in several instances macrobotanical remains from early strata in the Andes and elsewhere have been directly dated to later times periods. For example, at Quelcatani Cave, an Archaic period hunter-gather site located on the western shores of Lake Titicaca, chenopods were found in a stratum dating to 3000 BCE; however, direct AMS dating of these seeds indicated they were later intrusions (Eisentraut 1998; Planella et al. 2015).

The best evidence of the timing and location of chenopod domestication in the Altiplano comes from research spearheaded by Maria Bruno and her colleagues on macrobotanical remains from the southern shores of Lake Titicaca at the site of Chiripa, where she documented morphological change in macrobotanical seeds and directly dated them to *c.*1500 BCE (Bruno 2006; Bruno and Whitehead 2003). Since the seeds she securely dated were already domesticated, her findings indicate the process of cultivation and plant breeding of chenopods was probably well underway centuries earlier. Bruno and her colleagues documented this process of domestication using multivariate qualitative and quantitative techniques to identify morphological changes in ancient chenopods seeds over time attributed to human selection (Bruno 2006; Bruno and Whitehead 2003; Bruno et al. 2018; Langlie et al. 2011). This approach relies on measurements and assessments of attributes through low-powered binocular light microscopes, and more detailed measurements using scanning electron microscopy (SEM). To establish a baseline for what is considered domesticated quinoa, domesticated kañawa, weedy, or wild among Andean chenopods, she analyzed specimens of modern chenopod species (Bruno 2006; Bruno et al. 2018). The seeds she used were collected from farmers in the Bolivian Altiplano, as well as from seed banks in Bolivia. Measurements of these seeds provided a baseline for further research with which to classify ancient specimens.

Using these baselines, Bruno and Whitehead (2003) analyzed chenopods from the aforementioned Formative period site, Chiripa. They found that chenopods were smaller than any modern ones, but specimens possessed distinct characteristics of domestication, including a thinner seed coat compared to the seed diameter ratio. They also identified examples of quinoa negra, notably, in higher quantities in early contexts and lower amounts in later Formative contexts. This indicates that Chiripa residents began to meticulously weed their fields as the

Formative period progressed (Bruno and Whitehead 2003). Above all, this research was the first of its kind to quantify that domesticated quinoa was a staple food crop for Formative period populations living on the shores of Lake Titicaca by 1500 BCE (Bruno and Whitehead 2003).

Building on this research, Langlie et al. (2011) used Bruno's measurements of modern seeds as a baseline to describe another Formative period domesticated chenopod variety from central Bolivia by a culture group known as the Wankarani. This research found that a distinct domesticated variety was grown in the southern Altiplano by agropastoralists living in a small village known as La Barca around 1200 BCE (Langlie et al. 2011). In new research on agropastoral plant use, this variety, with a distinct prominent beak, was not identified in nearby Formative period Wankarani sites, even though La Barca is located only 25 miles to the west (Langlie and Capriles 2021). These findings indicate that distinct quinoa and kañawa varieties were likely grown by different Wankarani groups. Chenopod ecotypes, or in other words crops adapted to different hyperlocal environments, were grown by Altiplano farmers. High degrees of seasonal mobility of the Wankarani, due to seeking new pasture for camelid herds, meant that farmers were likely planting seed stock in different environments on an annual or biannual planting calendar. This would have exposed chenopod seed stock to a wide range of growing conditions, as well as the pollen of wild relatives naturally adapted to different habitats. As such, agropastoral mobility patterns typical of the Altiplano in the past and today would have positioned farmers to access diverse gene stock, producing crop varieties adapted to different local habitats and regions.

Other Crops in the Altiplano

A multitude of other crops were domesticated in other parts of South and Central America, eventually ending up in the fields, kitchens, and dinner plates of Altiplano people, including cotton, coca, sweet potatoes, jicama, chili peppers, peanuts, gourds, and even chocolate. Maize (*Zea mays* L.) was a particularly important crop that was domesticated elsewhere and ended up in the Altiplano. It was first domesticated in Central America and became a mainstay in the economy of the Altiplano between 400 and 1000 CE (Wright et al. 2003). Due to the high elevation-creating hypoxic environment of the region, maize does not grow particularly well in the Altiplano. Botanists suggest that, in fact, maize does not grow readily above 3,600 masl. Nonetheless, ancient farmers in the Altiplano bred varieties, locally referred to as *tunqu*, near the southern shores of Lake Titicaca (fig. 9). Farmers still grow tunqu there on agricultural terraces up to elevations of 4,100 masl (Staller 2016). In addition to the ancient selective breeding efforts of farmers, the lake moisture mediates diurnal changes in temperatures in this location, thus making it possible to cultivate this phenotypically unique variety. This is the only instance of farmers growing maize at this high of an elevation anywhere in the world (Staller 2016). Perhaps other high-altitude farmers will adopt tunqu into their crop portfolio in the future. Nonetheless, archeobotanical research on ancient maize indicates it was largely an import crop in ancient Altiplano cities, from lower elevation colonies (Hastorf et al. 2006). While exotic crops are part of the Altiplano diet and economy today, and probably have been at varying times in the ancient past, they were not domesticated in the south-central highland Andes. The vast array of locally domesticated chenopod and tuber varieties continues to serve as the nutritional foundation of diet in the Altiplano today.

Figure 9. An endemic variety of high-altitude maize grown in the Altiplano locally referred to as tunqu.

Source. Photo by author.

Models of Domestication

To understand domestication in the Andes, it is important to be familiar with the models that underpin and drive this body of research. These models range from evolutionary perspectives to more human-centered models. Here, I provide a brief overview of this body of literature.

Geophagy: The Chemical Ecological Model of Tuber Domestication

One of the obstacles that humans had to overcome to domesticate potatoes was the fact that wild potatoes, like other plants in the *Solanum* sp. genus, contain high levels of toxic glycoalkaloids. These glycoalkaloids provide protection for the growing plant from insects, fungi, and animal predators. As such, these chemical compounds also cause gastrointestinal issues and neurological disturbances for humans (Johns 1986). Selecting varieties of crops that contain lower levels of toxic glycoalkaloids, as compared to their wild counterparts, was an essential step in the domestication of many of the world's major crops (Rindos 1980). Potatoes were no exception. Boiling was one way to rid many of the world's crops of harmful chemicals, but the glycoalkaloids in potatoes do not dissolve in water or heat. Eventually, humans bred varieties of potatoes with very low levels of glycoalkaloids so that we can easily digest them. Nonetheless, this begs the question: How did the first hunter-gathers of the Andes eat toxic wild potatoes? And why are farmers still producing some potato varieties with comparatively high levels of this compound? The answer lies in a model of domestication proposed by Johns (1986). It has been established that particular naturally occurring clays have minerals in them that bind to glycoalkaloids, making them taste less bitter and be easily digested by humans (Johns 1986, 1989; Ralla et al. 2012). In the markets of Puno, Peru, and La Paz, Bolivia, you can still purchase culinary clay that people whisk into gravy-like recipes with salt and water, and potatoes are dipped in this slurry. Johns (1986) argues that toxic potatoes were originally a famine or fallback food that was opportunely ingested by hungry hunter-gatherers. Geophagy, or eating soil to meet particular mineral needs, has been practiced by human groups for millennia. Johns (1986) notes that, eventually, hunter-gatherers figured out that geophagy allowed humans to regularly consume toxic potatoes. Researchers have confirmed that geophagy in the Altiplano dates back to at least 500 BCE. Archaeologists found bits of clay and mineral residues typical of culinary clays on ceramic sherd fragments from securely dated contexts at the Formative period site Chiripa located on the southern shores of Lake Titicaca (Browman and Gundersen 1993). High levels of glycoalkaloids were bred out of most potato varieties, but unlike other crops with toxic compounds, humans still cultivate the toxic ones. Growing potatoes with varying levels of glycoalkaloids has provided farmers' fields with natural defenses against pests and disease. Future research on potato domestication and geophagy has the potential to illuminate the deep history of this practice and the health effects of it.

Mutualism: Pastoralism and the Camp Follower Hypothesis

Mutualism is an interaction between species that reciprocally benefits both organisms (Boucher 1985). In the Andes, mutualism is fundamental to farming success. Cultivating crops and practicing animal husbandry hedges against the risk of failure of any one crop or loss of alpacas or llamas, and one can be substituted for another in lean years (Browman 1987). In this way, the reciprocal relationship between crops, herds, and humans ensures the vitality of all three. It has been suggested that camelid herding (llamas and alpacas) played a role in the domestication of crops in the highland Andes (Kuznar 1993; Pearsall 1989). This model elaborates on the camp follower hypothesis in which small-seeded plants that thrived in anthropogenic settings colonized human habitats, drawing these plants into closer mutualistic relationships with humans; these plants were then more likely to be selected and consumed by humans because of proximity and familiarity (Anderson 1952; Sauer 1952). Pastoralism seems to have played a central role in facilitating quinoa propagation near human settlements (Kuznar 1993; Pearsall 1989). In this model, camelids eat wild chenopods, defecate near human settlements or in corrals where they are kept at night, thereby sowing, fertilizing, and multiplying these undigested seeds within the realm of human homes. Ethnographic work bolsters this hypothesis by providing evidence that wild chenopods are preferred camelid forage food and seeds often end up intact in llama dung (Hastorf and Wright 1998). Early herding practices would have concentrated wild chenopods in human habitats through selective forage and reseeding. If this model is correct, then pastoralists and their mobile lifestyles played a central role in domesticating chenopods. Further paleoethnobotanical research on Late Archaic period sites in the Altiplano region may shed light on the origins of these early mutualistic relationships between humans, camelids, and chenopods.

Along these same lines, it is very possible that a pastoral lifestyle also facilitated the domestication of Andean tubers. Ethnographic research indicates that planting tubers requires significantly less field preparation than planting seed crops, they take very little work to tend, the part of the plant above ground does not need to be defended from other predators the way seed crops do, and they are storable for a period of time if left in the ground (Hildebrand 2007). Early

21st-century paleoethnobotanical research on Formative period pastoralists in the central Altiplano near Oruro, Bolivia, indicates that tubers were cultivated as a part of the economy of early mobile pastoralists (Langlie and Capriles 2021).

Crop Diversity: Trade and Transhumance

The diversity and array of potato and quinoa varieties grown by Indigenous Andean farmers is astounding. It has been hypothesized that this diversity is a result of the economic trade and exchange networks that have long characterized Andean economies and lifeways (Langlie and Capriles 2021). Altiplano people have engaged in long-distance trade with neighbors and family members living at lower elevations and in different ecosystems (Murra 1972) since the Archaic period (Aldenderfer 1998). Facilitated by large llama caravans moving goods, symbolically important commodities, such as maize and coca, have long been traded between regions in the Andes (e.g., see Browman 1978, 1984). This trade and exchange was likely an important part in the development of the diverse crop varieties in the Andes. Andean tubers are vegetatively propagated. In other words, cut portions of tubers are planted to generate offspring, rather than by seed like their grain crop counterparts. Vegetative propagation results in offspring genetically identical to the mother plant, so there is very limited selection between generations. However, growing crops in multiple regions results in varieties adapted to thrive in various climates, different soil conditions, different photosensitivity requirements (day lengths), and different tolerances to diseases and pests due to increased exposure to a wide range of conditions and out-crossing with wild relatives (Borlaug 2007). Due to the vertical ecology of the Andes, the transhumance of pastoral populations, and trade and exchange relationships, farmers were exposing their crops to different ecosystems that placed selective pressures on plants, resulting in highly diverse array of landraces (Langlie and Capriles 2021). As a result, farmers are maintaining hundreds and thousands of ancient landraces of quinoa and tubers across the Altiplano and, more broadly, the Andes today. Indeed, trade, exchange, and transhumance, dating back to the Formative, may explain the diversity of chenopods found among Formative period pastoral sites in Oruro (Langlie and Capriles 2021), or the colorful varieties of chenopods documented in the Late Intermediate period (LIP) context from Potosí, Bolivia (López and Nielsen 2013). Further detailed archaeological research has the potential to identify precisely when, where, and, in some cases, why particular crop varieties were bred in the ancient Andes.

Gathering and Plant Breeding in the Era of Agriculture

The Importance of Wild Plants

Even though agriculture became a mainstay of Andean cuisine shortly after tubers and chenopods were domesticated in the Altiplano, it is important to note that farmers continued to seek out and value wild plant resources for food, seasoning, and raw materials in construction and handicrafts. Indeed, during the period of incipient plant and animal domestication, or the Late Archaic period, archaeologists have found that the number of edible wild plants almost doubled compared to earlier time periods in sites throughout the southern Andes (Ugalde et al. 2021, 219). This same study also found that wild edible plants continued to be important mainstays in the economy of Andean people at least up until the 15th century when the Inka built their pan-Andean Empire. These data show that there was no clear-cut transition from a hunting and gathering lifestyle to a commitment to farming; rather, when Andean people started farming, they continued to gather and hunt. While the importance of wild plant resources is often glossed over once agriculture arrives on the scene in world prehistory, Korstanje (2017) makes an excellent case for us to consider the importance of these wild resources in everyday life, particularly in the Andes. In addition to being important sources of nutrition, these wild plants are potentially the weeds that made a quotidian meal of potatoes and quinoa a flavorful culinary adventure (Hastorf and Bruno 2020).

Ongoing Domestication

Since domestication is an ongoing coevolutionary process, it does not end with the Neolithic period. Rather, plant breeding continues through time and paleoethnobotanists are just starting to study these long-term processes (Langlie 2019). With this in mind, it is important to consider these long-term processes from the perspective of the plants themselves. Archaeological research indicates that chenopod crops in particular thrived even though cultures and polities waxed and waned through time. By the Middle Horizon (400–1100 CE) power coalesced into the first state-level urban society in the region, known as Tiwanaku; chenopods were one of the most ubiquitous and abundant crops recovered from all archaeological contexts in the urban core of the city of Tiwanaku (Wright et al. 2003). These findings indicate that quinoa was a mainstay for all people living at Tiwanaku, regardless if they were wealthy elite, lower-class residents, or llama caravaners just stopping through on a trading expedition.

Around 1100 CE, the Tiwanaku state collapsed; at the same time colder temperatures and a long-term drought ravaged the environment of the highland Andes (Binford et al. 1997; Stanish 2003). Even though these cultural and climatological processes transformed life in the Andes during the LIP (1100–1450 CE) chenopods continued to be a mainstay in the economy of domestic cuisine, as documented through paleoethnobotanical analysis of macrobotanical remains from archaeological sites located west of Lake Titicaca near Puno, Peru, in the northern Altiplano, as well as in defensive fortification near Potosí, Bolivia, in the southern Altiplano (Langlie 2019; Lopez and Nielsen 2013; López et al. 2012). Desiccated remains from the Potosí region indicate that farmers were growing an array of different-colored quinoa varieties, including white, orange, pink, and black (cited in Planella et al. 2015; after López 2012). Residents living near Puno were growing both quinoa and kañawa and were intensively weeding their fields. Even though the LIP occurred over two centuries after domestication of chenopods, seeds were still smaller than their modern counterparts (Langlie 2019). Quinoa continued to be an agricultural staple and mainstay in the diet of Andean peoples throughout the Inka and Colonial eras (National Research Council 1989, 151), and breeding Andean chenopod crops continues today.

The varieties of potatoes and quinoa consumed around the world are the ancestors of ones bred for generations by Indigenous farmers in the ancient Andes. These staples provided sustenance for the rise and fall of Andean civilizations, including the Tiwanaku state and the Inka Empire, as well as Colonial period Indigenous and Spanish people. Nonetheless, the varieties that are abundantly available today look a little different. Modern varieties have been bred for mass production, global markets, and modern culinary preferences. A literal rainbow of colors and varieties of quinoa, kañawa, potatoes, oca, maize, and other tubers are still grown in the Altiplano. These varieties have been bred over the past several millennia for their colors, flavors, salt tolerances, and drought, disease, and pestilence resistance. As we are seeking diversity in our own global cuisine, and solutions to food security challenges going forward, it is possible that farmers of the Altiplano already have the answers growing in their fields. Understanding the origins of agriculture speaks to not only the history of these crops, but also lends insight into how, why, and where these varieties were developed.

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