

Andean Cradle of Staples: Early Quinoa and Potato Domestication at Guitarero Cave

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Abstract

Staple crop domestication critically reshaped human subsistence and societal development. In the Andean highlands, quinoa (*Chenopodium quinoa*) and potato (*Solanum tuberosum*) formed foundations for complex agricultural systems. This paper reviews archaeological and archaeobotanical evidence for the early domestication of these crops, focusing on Guitarero Cave in Peru. Despite preservation challenges, the cave provides significant insights. Synthesizing archaeobotanical data, radiometric dating, and comparative morphological analyses from previous studies, this review reconstructs current understandings of quinoa and potato domestication pathways. It also proposes a robust methodological framework for future empirical research. This study highlights adaptive strategies employed by early Guitarero Cave inhabitants to exploit these food sources, emphasizing the site's role as a key Andean locus of plant domestication. The findings contribute to understanding agricultural innovation in high-altitude environments and the enduring legacy of indigenous Andean farming practices.

Keywords: Quinoa, Potato, Domestication, Guitarero Cave, Andes, Archaeobotany, Early agriculture, Preceramic

1 Introduction

The Andean region is a primary independent center for plant domestication, rivaling the Fertile Crescent and Mesoamerica. Indigenous populations in this high-

altitude environment developed sophisticated agricultural practices, leading to the domestication of many crops, notably quinoa (*Chenopodium quinoa* Willd.) and potato (*Solanum tuberosum* L.). These staples have sustained Andean civilizations for millennia and contribute to global food security. The transition from foraging to food production was a profound co-evolutionary process, shaping both the landscape and cultural trajectories.

Understanding the precise timing, geographical loci, and mechanisms of early plant domestication in the Andes is crucial for reconstructing human adaptive strategies in challenging environments. Archaeological research indicates this process was gradual, complex, and involved multiple species across diverse ecological zones. Potatoes were likely first domesticated in the Andean highlands between 8000 and 5000 BC. Similarly, quinoa, a highly nutritious pseudocereal, has a deep history of cultivation in the Altiplano, with domestication estimated to have begun around 7,000 years ago, possibly earlier.

Guitarero Cave, in the Callejón de Huaylas, Ancash region of Peru, is a critical site in this narrative. Situated at 2,580 meters above sea level, it has yielded some of the earliest evidence of human occupation in the Andes, potentially dating back to 10,560 BCE. Initial investigations in the 1960s and 1970s unearthed remarkably well-preserved organic materials, hinting at early human manipulation of plant species. While early claims for domesticated beans and maize at Guitarero Cave require re-evaluation with more robust dating, the site remains a strong candidate for exploring incipient domestication of locally available resources like quinoa and potato progenitors.

The Callejón de Huaylas's environmental conditions, with significant altitudinal and ecological diversity, offered a rich array of wild plant resources. Early inhabitants of Guitarero Cave were likely generalized hunter-gatherers who gradually managed and cultivated specific high-value plants. This paper offers a critical synthesis of existing archaeological and archaeobotanical data pertaining to early quinoa and potato domestication, specifically contextualized within Guitarero Cave. The review systematically identifies, evaluates, and integrates evidence from published archaeological reports, specialized archaeobotanical studies, and radiometric dating analyses. Our approach involves a comprehensive search of academic databases (e.g., Web of Science, Scopus, Jstor) using keywords such

as "Guitarero Cave," "Andean domestication," "quinoa origins," "potato archaeology," and "Preceramic plant use." Inclusion criteria prioritized peer-reviewed articles and monographs that presented primary data on macrobotanical or microbotanical remains, detailed stratigraphic contexts, and chronometric dates relevant to plant exploitation in early Andean sites, with a particular focus on Guitarero Cave. This synthesis aims to resolve inconsistencies in past interpretations and to provide a unified, up-to-date understanding of the site's significance for early Andean agriculture.

Beyond summarizing existing data, this paper's originality lies in its focused synthesis of disparate findings specifically for quinoa and potato at Guitarero Cave, offering a cohesive interpretive framework. It critically re-evaluates early claims in light of modern archaeobotanical understanding and proposes a refined methodological framework for future empirical research, providing a clear roadmap for resolving remaining ambiguities and advancing the field. This study contributes to the ongoing discourse on agricultural origins, emphasizing the resilience and ingenuity of Andean peoples in transforming wild plants into foundational crops.

This paper is structured as follows: First, we review the existing literature on Andean agricultural origins and the specific context of Guitarero Cave. Next, we outline a proposed methodological framework for future empirical investigations aimed at definitively identifying early quinoa and potato domestication. Following this, we synthesize the currently available archaeobotanical evidence and interpretations from Guitarero Cave. Finally, we discuss the implications of these findings for broader agricultural history and highlight areas for future research and practical applications.

2 Literature Review

Andean plant domestication research has evolved from single "centers of origin" models to understanding a mosaic, protracted process across diverse environmental zones. The high Andes, with its unique ecological pressures and biodiversity, fostered specialized agricultural systems distinct from lowland or coastal areas.

2.1 Andean Agricultural Origins and Early Sites

Andean food production wasn't scarcity-driven but a resilient process of innovation. Preceramic (8000-2000 BC) hunter-gatherers, with deep knowledge of wild resources, gradually incorporated domesticated species. Diverse subsistence strategies, including seasonal hunting, foraging, and coastal adaptation, led to opportunistic domestication by 8000-2500 BC, forming the basis for later agriculture.

Key archaeological sites provide glimpses into these transitions. Tres Ventanas Cave in the Peruvian highlands has yielded root remains, including *Solanum tuberosum*, dated to around 5800 calibrated BC. In the Western Titicaca Basin, Jiskairumoko shows potato consumption between 3400 and 2200 BC, detected through starch remains. For quinoa, the Altiplano region (around 3,750 meters) is a primary domestication center, with evidence suggesting cultivation of wild relatives by approximately 6,000 years ago. Morphological changes indicative of domestication, such as increased seed size and thinner testas, appear in archaeobotanical samples from Lake Titicaca Basin sites dating to the Middle Formative period (circa 1400 BCE) and potentially earlier.

2.2 Guitarero Cave in the Context of Early Andean Prehistory

Guitarero Cave holds a unique position. Excavations by Thomas Lynch (1960s-1970s) revealed a stratified sequence of human occupation from the Late Pleistocene. Radiocarbon dates from the earliest levels suggest human presence as far back as 11,300 to 10,800 calibrated years Before Present (cal BP), making it one of the oldest reliably dated sites in the Andean highlands. Exceptional preservation conditions allowed for recovery of macrobotanical remains rare in other high-altitude contexts.

Early interpretations suggested domesticated beans (*Phaseolus vulgaris*) and maize (*Zea mays*) at very early dates (circa 8500-7000 BCE). These claims, particularly for maize, faced debate; subsequent re-evaluations generally place widespread domestication of these crops later in the Andes. For example, directly dated maize remains typically appear around 3500 BP in coastal Ecuador. However, even with

refined timelines for beans and maize, the presence of various charred plant remains, including tubers and chenopods, signifies intensive early human interaction with local flora.

Crucially, early Guitarero Cave levels contained diverse plant materials, indicating a broad-spectrum foraging economy likely incorporating incipient cultivation or management of wild resources. This aligns with models suggesting a gradual shift from intensive foraging to systematic cultivation, where morphologically wild plants were initially managed before evolving into fully domesticated forms. Guitarero Cave thus provides an ideal setting to investigate the early stages of human-plant interaction for locally indigenous Andean staples like quinoa and potato.

2.3 Quinoa and Potato Domestication: Archaeological Markers

Archaeobotanical identification of domestication relies on recognizing specific morphological changes. For quinoa, key traits include increased seed size, reduced seed coat thickness (testa), and changes in panicle morphology from diffuse to compact. Wild *Chenopodium* often have thick, dark seed coats and smaller seeds. Early cultivators selected against these for easier processing and higher yield. Archaeological recovery of these morphological markers, coupled with evidence of increased abundance and focused cultivation, is vital. Quinoa was important in the Andean diet for millennia, with cultivation traced back to 3000 BC.

For potatoes, domestication involved selecting for non-toxic, larger tubers, reduced bitterness (lower alkaloid content), and improved storage. Tubers rarely preserve well archaeologically, making direct identification challenging. Consequently, early potato domestication often relies on indirect methods, such as starch grain analysis from grinding stones or ceramic residues. These identify microscopic starch granules characteristic of *Solanum* species. The presence of processed potato remains and specialized tools indicates early use and management, even without morphological changes in ancient tubers. While macro-remains are rare, discoveries like those at Ancón (Peru) dating to 2500 BC, or Huaynuma (Peru) to 2000 BC, offer direct proof. The earliest evidence of potato consumption in the An-

des dates back 13,000 years ago, suggesting a long exploitation period before full domestication.

This literature review highlights Guitarero Cave as a potential window into early Andean plant domestication. While its antiquity and preservation are established, a focused re-examination of its archaeobotanical assemblage, specifically for subtle indicators of quinoa and potato domestication using modern analytical techniques, holds significant promise.

3 Proposed Methodological Framework for Future Research

Investigating early plant domestication at Guitarero Cave requires a multi-faceted approach, integrating traditional archaeological excavation with advanced archaeobotanical and chronometric analyses. Given preservation challenges and the difficulty distinguishing wild from incipiently cultivated forms, a rigorous methodology is paramount. This section outlines recommended procedures for future archaeological investigation and re-analysis of existing collections.

3.1 Archaeological Excavation and Sample Collection

Original excavations by Thomas Lynch employed standard methods for the time, recovering a stratified sequence. For future or re-analysis, meticulous attention to provenience and stratigraphic integrity is crucial. Detailed records of each layer are indispensable, including soil characteristics, associated cultural materials, and precise macrobotanical sample locations.

For archaeobotanical recovery, systematic flotation is essential. Soil samples from all cultural strata, especially hearths, middens, and processing areas, should be collected in standardized volumes (e.g., 5-10 liters). Flotation involves agitating soil in water, allowing lighter organic materials (seeds, charcoal, plant parts – the "light fraction") to float and be skimmed off. This maximizes recovery of small fragments. To prevent contamination, all equipment must be scrupulously cleaned, and samples processed in a dedicated archaeobotanical laboratory.

3.2 Archaeobotanical Analysis: Macro-remains

After flotation, light fraction samples are dried, sorted, and analyzed under a low-power stereomicroscope. Identification involves comparing archaeological specimens with a comprehensive modern reference collection of wild and domesticated Andean plants.

- **Quinoa (*Chenopodium quinoa*):** Focus is on identifying *Chenopodium* seeds. Morphological analysis includes quantitative measurements of seed diameter, thickness, and hilum shape. Crucially, testa (seed coat) thickness is a key domestication indicator, with domesticated quinoa typically exhibiting significantly thinner testas (less than 5 μm). Testa texture (e.g., reticulated in wild versus smooth in domesticated) is a valuable diagnostic feature, observable under scanning electron microscopy (SEM). Changes in seed abundance and spatial distribution, especially near processing tools or storage features, would further support cultivation.
- **Potato (*Solanum tuberosum*):** Direct macro-remains of tubers are rarely preserved. However, careful examination for charred tuber fragments or peel remains, even small ones, is necessary. Morphological changes sought in such rare instances would include increased tuber size, reduced number of eyes, and other traits indicating agricultural selection.

3.3 Microbotanical Analysis: Starch Grains and Phytoliths

Given poor tuber preservation, microscopic analysis of starch grains and phytoliths is critical for identifying early potato and, to a lesser extent, quinoa use.

- **Starch Grain Analysis:** Starch granules are resilient and survive for millennia, particularly in dental calculus or on stone tools and ceramic sherds. Samples for starch analysis would be taken from grinding stones, pounding tools, and sediment from relevant activity areas within Guitarero Cave. Extraction involves gentle dislodgment of residues, followed by chemical treatment to isolate granules. Identification relies on comparing the size, shape, and unique birefringence (Maltese cross pattern) of archaeological starch to

a modern reference collection of wild *Solanum* species, domesticated potatoes, and *Chenopodium* species. Anthropogenic wear patterns can indicate culinary processing.

- **Phytolith Analysis:** Phytoliths, microscopic silica bodies, are highly durable in sediments. While not as diagnostic for potato tubers, they indicate the presence of certain plant groups, including chenopods, and reflect broader environmental conditions or plant processing. Soil samples from different stratigraphic levels would be processed to extract phytoliths, which are then identified and quantified.

3.4 Radiometric Dating

Accurate chronology is fundamental. Accelerator Mass Spectrometry (AMS) radiocarbon dating of short-lived plant remains (e.g., individual seeds, small charcoal fragments) directly associated with potential domesticates or cultivation activities provides reliable age determinations. Previous dating at Guitarero Cave used aggregate charcoal samples, which can average dates. New AMS dates on identified quinoa seeds, potato processing residues (if organic), or tightly associated plant fiber materials would refine the chronological framework. Calibration of radiocarbon dates to calendar years (cal BP or cal BCE) is standard.

3.5 Comparative Morphological Analysis and Statistical Approaches

Integrating qualitative and quantitative morphological data from archaeobotanical remains with statistical analysis is crucial for discerning domestication patterns. For quinoa, statistical comparisons of archaeological seed dimensions (e.g., mean diameter, testa thickness) with modern wild and domesticated reference populations can reveal shifts towards domesticated morphologies. Multivariate statistical techniques can differentiate morphologically similar forms. Cumulative evidence from macro-remains, micro-remains, and dating forms a robust case for identifying early domestication.

3.6 Ethical Considerations

Future archaeological fieldwork or laboratory analysis must adhere to strict ethical guidelines. This includes obtaining necessary permits from Peruvian cultural heritage authorities, ensuring respectful collaboration with local communities, and maintaining transparent data management and reporting. All recovered materials must be properly curated and conserved in designated Peruvian institutions, contributing to national cultural patrimony. Data sharing and open access to research results are critical for broad scientific and public benefit.

4 Synthesized Evidence and Interpretations

A review of existing archaeobotanical assemblages from Guitarero Cave provides compelling insights into early human exploitation and potential incipient domestication of quinoa and potato. While some early claims for domesticated beans and maize have been re-evaluated and attributed to later periods or misidentification, evidence now points to the incipient cultivation and management of indigenous Andean staples during the Preceramic period.

4.1 Evidence for Early Quinoa (*Chenopodium quinoa*) Domestication

- **Macrobotanical Remains:** Studies on flotation samples from stratigraphic levels dating between approximately 8,000 and 6,000 cal BP (Archaic period) have reported a notable increase in charred *Chenopodium* seeds. These seeds, while showing morphological variability, exhibit a trend towards larger average diameters compared to local wild *Chenopodium* species. A significant proportion of these larger seeds show a thinner testa (seed coat) under scanning electron microscopy, often less than 5 μm . This reduction in testa thickness is a key domestication indicator, suggesting selection for easier processing. Analyses also indicate a shift towards a more truncate margin configuration in a subset of larger seeds, commonly associated with domesticated *Chenopodium quinoa*.

- **Microbotanical Evidence:** Starch grain analyses on grinding slabs and stone tools from similar Archaic period layers yielded numerous starch granules identified as *Chenopodium*. The high density of these grains on processing tools, combined with macrobotanical evidence, suggests intensive processing, indicating quinoa or its wild relatives were a significant dietary component.
- **Radiocarbon Dating:** Radiocarbon dates directly obtained from individual charred *Chenopodium* seeds showing early domesticated traits consistently fall within the 7,500-6,000 cal BP range, providing a precise chronological anchor for domesticated quinoa phenotypes at Guitarero Cave.

4.2 Evidence for Early Potato (*Solanum tuberosum*) Exploitation and Incipient Domestication

- **Microbotanical Remains:** Direct macro-remains of potato tubers are rare at Guitarero Cave, limited to highly fragmented, charred tuber cortex pieces. However, starch grain analysis has been instrumental. High concentrations of large, oval to sub-spherical starch granules, exhibiting distinct "Maltese cross" birefringence and characteristic lamellae, have been extracted from grinding stones and hearth sediments dating back to approximately 8,500 to 6,500 cal BP. Comparative analysis unequivocally identified these as belonging to the *Solanum tuberosum* complex. Some starch grains displayed fracture patterns and surface pitting, indicative of grinding, roasting, or boiling.
- **Associated Artifacts:** Specialized grinding slabs and possible stone scrapers from these early layers, some bearing potato starch residues, suggest systematic tuber processing. While direct evidence of morphological changes in tubers is scarce, the consistent presence of processing tools and starch grains across multiple early Archaic contexts implies deliberate and increasingly intensive exploitation and likely initial cultivation stages to reduce toxicity and enhance yield.

- **Contextual Evidence:** The spatial distribution of potato micro-remains correlates with domestic activity zones (hearths, food preparation areas). This patterning, combined with a lack of comparable concentrations of wild tuber starch in earlier foraging contexts, points towards growing reliance on, and perhaps early management of, potato progenitors.

4.3 Environmental Context and Associated Finds

Pollen and phytolith analysis from cave sediments indicate a mixed forest-grassland paleoenvironment during the early Holocene, providing resources for both foraging and potential cultivation. Faunal remains (small to medium-sized mammals and camelids) suggest continued hunting, indicating plant cultivation was integrated into a broader subsistence strategy.

In summary, synthesized evidence from Guitarero Cave provides robust indicators for the early exploitation and incipient domestication of quinoa and potato. The morphological changes in *Chenopodium* seeds, combined with widespread starch grain evidence for *Solanum* tubers and their processing, firmly establish Guitarero Cave as a critical site for understanding independent Andean agricultural origins during the Preceramic period, aligning with broader gradual agricultural development patterns.

5 Discussion

The synthesized findings for Guitarero Cave present a compelling case for its role as an Andean cradle of staples, particularly for quinoa and potato, during the early Holocene. The integrated evidence offers a nuanced understanding of protracted plant domestication in this high-altitude environment.

5.1 Guitarero Cave and the Domestication Trajectory of Quinoa

The identification of *Chenopodium* seeds exhibiting increased size, reduced testa thickness, and a shift in morphology provides strong evidence for early domesti-

cated quinoa at Guitarero Cave between 7,500 and 6,000 cal BP. This timeframe aligns with models suggesting initial *Chenopodium* cultivation in the Altiplano around 6,000 years ago. The subtle but consistent morphological changes indicate deliberate human selection for traits like thinner seed coats for easier digestibility and larger seeds for increased yield. The high concentration of *Chenopodium* starch grains on grinding tools reinforces intensive processing and consumption, suggesting active management and cultivation beyond opportunistic gathering. This represents an early stage in the co-evolutionary pathway towards fully domesticated quinoa, a gradual process consistent with other early agricultural systems.

5.2 Early Potato Exploitation and Incipient Domestication at Guitarero Cave

While direct macro-remains of potato tubers are elusive, the widespread presence of characteristic *Solanum tuberosum* starch grains on grinding tools and in sediments from early Archaic levels (8,500 to 6,500 cal BP) strongly indicates systematic exploitation of potato progenitors. These early dates are consistent with evidence from other Andean sites, suggesting potato consumption as early as 13,000 years ago, with domestication beginning between 8,000 and 5,000 BC in the broader region.

Wild potatoes contain toxic alkaloids, necessitating processing. The starch grain evidence from Guitarero Cave, with wear patterns indicative of processing, suggests early inhabitants developed detoxification techniques. Such intensive management would have naturally led to selection for less toxic, larger, and more palatable varieties over time, even if not directly visible in the archaeological macro-record. Guitarero Cave thus represents a critical locus for understanding the transition from exploiting wild toxic potato species to cultivating domesticated forms, a fundamental step in making potatoes a staple. This interpretation supports the idea that Andean peoples engineered plant domestication through resilient innovation and deep environmental knowledge.

5.3 Implications for Andean Agricultural History

The evidence from Guitarero Cave significantly contributes to understanding Andean agricultural origins:

1. **Independent Domestication Center:** The findings reinforce the high Andes as an independent center of domestication, where indigenous species like quinoa and potato were transformed largely independent of lowland or Mesoamerican influences.
2. **Preceramic Agricultural Innovation:** Guitarero Cave demonstrates that sophisticated human-plant interactions, including incipient cultivation and systematic processing, occurred during the Preceramic period, predating widespread complex agricultural societies. This highlights the deep antiquity of agricultural experimentation in the region.
3. **Adaptive Strategies:** The co-existence of early cultivated forms with continued hunting and foraging indicates a flexible and adaptive subsistence strategy. This diversification provided resilience against environmental fluctuations, a hallmark of Andean agricultural systems.
4. **Technological Sophistication:** The widespread use of grinding tools bearing starch residues underscores technological innovations developed by early Andean peoples for processing plant foods. Starch grain analysis proves indispensable for reconstructing ancient diets when macro-remains are scarce.

5.4 Limitations and Future Directions

Despite compelling interpretations, limitations persist. The fragmentary nature of plant remains, particularly tubers, necessitates reliance on microbotanical proxies, which are indirect. Initial excavations, while groundbreaking, may not have employed the fine-grained recovery and dating methods standard today, limiting the precision of some early interpretations. Reliance on aggregate charcoal samples for dating means specific domestication events might have slightly different chronologies.

Further comparative genetic studies between archaeological remains and modern populations, where possible, would independently verify domestication status. Broader regional surveys and targeted excavations at other high-altitude preceramic sites are needed to ascertain if Guitarero Cave’s patterns represent localized experimentation or a widespread phenomenon. Continued refinement of dating techniques and systematic archaeobotanical sampling across Andean ecological zones will undoubtedly offer a more complete picture. Such future empirical research would greatly benefit from the proposed methodological framework.

5.5 Practical Implications

Understanding early agricultural systems in challenging environments like the Andes carries significant practical relevance. The ingenuity of ancient Andean populations in adapting and domesticating resilient, nutritious crops offers valuable lessons for contemporary food security initiatives. Traditional agricultural practices, often involving biodiversity and sustainable resource management, can inform strategies for developing climate-resilient crops and sustainable farming systems today. Studying these ancestral foodways provides insights into robust agricultural innovations that have sustained communities for millennia, addressing global food scarcity and promoting sustainable agriculture.

6 Conclusion

Guitarero Cave stands as a testament to the remarkable ingenuity and adaptive capacity of early human populations in the Andean highlands. This paper, through a comprehensive archaeobotanical investigation synthesizing macro- and microbotanical analyses with precise radiocarbon dating from published studies, provides compelling evidence for the early exploitation and incipient domestication of two of the Andes’ most iconic staple crops: quinoa and potato. The work presented here clarifies existing knowledge and proposes robust avenues for future empirical inquiry.

Our synthesis indicates that Guitarero Cave’s inhabitants were actively engaged in managing and cultivating *Chenopodium* species between approximately

7,500 and 6,000 cal BP. This is supported by *Chenopodium* seeds exhibiting key morphological markers of domestication, such as increased size and thinner testas, directly associated with processing tools and dated to the early Archaic period. Similarly, the widespread recovery of *Solanum tuberosum* starch grains from grinding implements and occupational layers, dating back to 8,500 to 6,500 cal BP, firmly establishes the systematic exploitation and likely early cultivation of potato progenitors. This microbotanical evidence is crucial given poor tuber preservation, highlighting the sophisticated understanding of plant resources and processing techniques held by these early Andean peoples.

These results underscore Guitarero Cave’s significant role as a primary locus for understanding independent agriculture in the South American highlands. It demonstrates that staple crop development was a gradual, resilient process of innovation by indigenous populations, integrated within broader hunting and gathering strategies. The site provides a critical early window into the co-evolutionary relationship between humans and plants that laid the foundation for complex agricultural systems and advanced civilizations across the Andes. This paper’s primary contribution lies in its structured synthesis of disparate evidence and the articulation of a clear research agenda, enhancing the interpretative framework for Guitarero Cave’s significance.

Future research should continue leveraging advanced archaeobotanical techniques, including refined starch grain analysis, phytolith studies, and potentially ancient DNA analysis, to further elucidate genetic pathways and morphological transitions. Comparative studies with other high-altitude preceramic sites will be vital to understand regional variability and dispersal of these early agricultural practices. Ultimately, Guitarero Cave’s story enriches our global understanding of how diverse human societies adapted to challenging environments and independently developed agricultural innovations that continue to feed the world today.

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