Agricultural Intensification at Cerro de Oro (Cañete Valley, Peru): Exploring the Use of Fertilizers through Stable Isotope Analysis

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Abstract

Agricultural Intensification at Cerro de Oro (Cañete Valley, Peru): Exploring the Use of Fertilizers through Stable Isotope Analysis

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Stable carbon and nitrogen isotope analysis of 571 archaeobotanical samples was performed to assess agricultural practices at Cerro de Oro in the Cañete Valley, Peru, during transition between the Early Intermediate Period and the Middle Horizon. This thesis presents a comprehensive range of δ^{13}C and δ^{15}N values for the major C_3 and C_4 plant resources at the site. No differences were found in the δ^{15}N values of charred and desiccated maize cobs, suggesting that both types of plant remains can provide reliable δ^{15}N measurements. Generally, the δ^{15}N values of plants at the site were relatively high, with the exception of most of the legumes, suggesting that organic fertilizers were extensively used. Camelid dung and fish offal are the most likely fertilizers used at Cerro de Oro, but some very high δ^{15}N values suggest that seabird guano may also have been used. Peanuts, a legume, had higher δ^{15}N values than would be expected for legumes, suggesting that this plant may have been companion-planted alongside maize or other more heavily fertilizer crops. Cotton had the highest δ^{13}C value among all of the C3 plants sampled from the site, suggesting that this crop grew in the driest conditions, possibly reflecting a deficit irrigation system. This study reveals how intensive and extensive agriculture supported the emergence and growth of Cerro de Oro, a monumental site of great regional importance.

Key words: Stable Isotope Analysis, Carbon, Nitrogen, Agriculture, Intensive, Extensive, Plants, Diet, Andean Archaeology, Central Coast, Early Intermediate Period, Middle Horizon, Cerro de Oro.

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> *Un montón de gente, un mar de fueguitos. Cada persona brilla con luz propia entre todas las demás. No hay dos fuegos iguales. Hay fuegos grandes y fuegos chicos y fuegos de todos los colores. Hay gente de fuego sereno, que ni se entera del viento, y gente de fuego loco, que llena el aire de chispas. Algunos fuegos, fuegos bobos, no alumbran ni queman; pero otros arden la vida con tantas ganas que no se puede mirarlos sin parpadear, y quien se acerca, se enciende (Eduardo Galeano: El libro de los abrazos).*

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1. Introduction

This research aims to study agricultural practices at the archaeological site of Cerro de Oro in the Cañete Valley, Peru. Specifically, I assess the ways in which the inhabitants of the site used fertilizers and irrigation to increase crop yields. Understanding these practices allows us to assess how the agricultural economy supported this growing monumental site of great regional importance. For this thesis, stable carbon and nitrogen isotope analysis of macrobotanical remains provided insight on the growing conditions of various crops, specifically the types and amounts of fertilizers that were used, as well as the relative importance of irrigation systems for crops (Fiorentino et al. 2015).

Cerro de Oro is in the Lower Cañete Valley, between Lima and Nasca. It was a large, monumental settlement with a continuous occupation from the end of the Early Intermediate Period (EIP) (500–600 CE) to Early Republican times (1540–1600 CE) (Fernandini 2015a, 2015b, 2018). The first of its four occupations (the Cerro de Oro occupation) ranges from 550 to 850 CE and covers the transition between the Early Intermediate Period and the Middle Horizon (MH) (600-900 CE). This is the period during which the site was most densely inhabited and saw a great amount of cultural development characterized by the emergence of local material culture, with foreign influences from cultures such as Lima, Nasca, and Wari. This site has been researched and excavated since the beginning of the 20th century by various researchers, such as Julio C. Tello (1925) and Alfred Kroeber (1937). Currently, the Cerro de Oro Archaeological Project (PACO) is directed by Dr. Francesca Fernandini (Fernandini 2015a, 2018a, 2020), who has excavated at the site since 2012.

A total of 571 samples from 31 plant taxa were analysed for this research project, all of which were collected from the archaeological site of Cerro de Oro, including: maize, pacae, lucuma, avocado, peanut, chili, and beans, representing the most economically important taxa. Most of the plant remains were desiccated rather than charred.

Isotope analysis on plants and specifically on crops reflect the environmental conditions under which the plants were grown (Fiorentino et al. 2015; Szpak et al.2012a, 2012b, 2014; Szpak and Chiou 2020). For example, high plant δ^{15}N values may be related to the use of natural fertilizers such as llama dung or seabird guano Boogard et al. 2007; Szpak et al.2012a, 2012b, 2014) burning/shifting cultivation or tillage and others forms of agricultural intensification (Szpak 2014). Guano has been an important part of the Andean economy since pre-Hispanic times and it is noteworthy that both this area and especially neighbouring southern areas have been historically known for the extraction of guano (Curatola 1997). Guano is produced by seabirds such as guanay (*Phalacrocorax bougainvillii*) and peruvian booby (*Sula variegata*), all of which are represented in the zooarchaeological record of Cerro de Oro, signifying almost 30% of the faunal remains recovered (González Gomez de Aguero 2019; Fernandini 2020). Although there are historical records of the importance of guano for agricultural systems (Julien 1985), no unequivocal archaeological evidence exists for its use in prehistoric contexts. The great abundance of seabird remains at Cerro de Oro suggests that this source of nutrients may have been crucial in the staple economy at the site. Regarding camelid dung, these animals represent around the 20% of faunal remains (by MNI). Camelid bones have been found within domestic contexts, some of them with cutmarks; camelid dung and camelid corrals have also been found at the site (González Gómez de

Agüero 2019). The use of fish carcasses as fertilizers should not be discounted as the site is close to the coastline. Anchoveta (*Engraulis ringens*) and other similar small fishes (González Gómez de Agüero 2019) as well as large silos to store, salt and desiccate fish (Fernandini 2019) were found at the site.

δ^{13}C values in plants can indicate the environmental conditions and also irrigation practices, since plant δ^{13}C values are especially sensitive to water availability (Fiorentino et al. 2015; Styring et al. 2017). The irrigation system that made most of the alluvial fan of the lower Cañete valley arable grew in relation with the emergence of Cerro de Oro. The construction of this monumental settlement of 150 ha was probably linked to environmental changes and the accessibility of water and food (Fernandini 2018b). The congregation of people around this site may have been associated with the construction and expansion of irrigation canals that brought water from the Cañete River to the site and/or to avoid climatic uncertainty and flooding caused by El Niño Southern Oscillation (ENSO) events. Nowadays, Cerro de Oro is surrounded by farmlands and the Cañete Valley is one of the most fertile valleys in Peru. Agricultural products represented a very important part of the diet of the inhabitants of the site on the basis of abundant botanical remains and it is clear that irrigation was necessary to support large scale agriculture (González Gomez de Aguero 2019; Fernandini 2018).

One of the important findings of this research is the reliability of desiccated plant remains for stable isotopes analysis. This is significant as most botanical remains recovered in central Andean coastal region are desiccated rather than charred. The isotopic data generated for plant remains from Cerro de Oro represent the most comprehensive set of regionally and temporally specific isotopic baselines for palaeodietary research in the Americas, and will therefore be of tremendous importance to future research. Regarding agricultural practices, this research presents data consistent with the use of natural fertilizers in some of the plant species found at Cerro de Oro. Also, the data provide insight into the extensive agricultural knowledge of the inhabitants within the use of irrigation systems, companion planting, and crop rotation as ways to increase agricultural yields and arable lands, in an intensive and extensive agricultural effort. This research allows us to better understand the importance of agriculture in the emergence and development of Cerro de Oro as one of the biggest and most important sites in the lower Cañete valley during the EIP to MH transition. Finally, this study highlights the importance of agriculture as one of the main economic activities that was crucial to the development of societies during the EIP.

This research is significant since it aims to characterize one of the main economic activities of Cerro de Oro and its impact on the large social and political transformations that occurred at this time. Finally, this research lays the foundations for future work in the region. Although isotopic analyses of botanical remain is well established in Europe and Asia, these techniques have not been applied in the Americas (Fiorentino et al. 2015).

Chapter 2 of this thesis presents a general Andean archaeological background from the Early Intermediate Period to Middle Horizon (MH), describing in more detail Lima, Nasca, and Wari societies as Cerro de Oro’s neighbours. The environmental and agricultural characteristics of this region and period are discussed, particularly as they relate to relevant aspects of this thesis. Finally, an exhaustive description of the archaeological site of Cerro de Oro and a brief review of the current state of isotopic studies in the Andes are presented. Chapter 3 provides an overview of stable isotope analyses of plants in archaeology as well as the underlying principles of how stable carbon and nitrogen isotopes vary in plant-soil systems. Finally, the background for methodological issues relating to the isotopic analysis of desiccated and charred plant samples from archaeological sites is discussed. Chapter 4 describes the samples analyzed as part of this thesis, providing an overview of the biological and cultural characteristics of the plant species that were sampled. The laboratory methods for sample preparation and analysis are also detailed in Chapter 4. Chapter 5 presents the results of this study and a discussion of their implications. The isotopic data from Cerro de Oro are compared to existing plant stable isotope data that have been used as baselines to interpret human and animal diet. The interpretations and archaeological implications of the isotopic data are discussed, particularly as they relate to agricultural practices during the EIP to MH transition, with an emphasis on crop fertilization practices. Finally, Chapter 6 summarizes the importance of these findings with respect to the nature of the site of Cerro de Oro and the agricultural practices in the Andes during this period.

1. Archaeological background:

1.1. Andean Archaeology: Early Intermediate Period (EIP) to Middle Horizon (MH) Transition (550-800 C.E.)

Andean archaeology has a few different ways to define chronology. One of the most widely used is the one proposed by John Rowe (1962). This chronology uses the term "horizon" to describe periods of great cultural expansion, and "intermediate" to describe periods of local and regional development. In Rowe's chronology, the Early Intermediate Period (EIP) started around 200 BCE with the loss of influence of the Chavin over the Andean territory. This period goes until 600 CE, when the Wari emerged and continued to be influential through the Middle Horizon. However, there are some other chronologies that define these periods in different ways, such as the one proposed by Lumbreras (1969a, 1969b). According to Lumbreras' chronology, the Middle Horizon is called Regional Developments and goes from 100 CE to 800 CE. Although it is difficult to establish a general chronology for all the Central Andes during this period, due to the different duration of cultural developments among regions, I will use Rowe's chronology within this research as is the most commonly used. Rowe's chronology is also the one used by the Archaeological Project of Cerro de Oro.

During the EIP there were different regional developments with the emergence of cultural traits forming what are traditionally known as 'cultures', now better defined as traditions or societies − human groups sharing cultural traditions, materials, and beliefs (e.g., Lima, Nasca, and Wari). The development of these societies all share the following four traits: the rise of the state, specialization in occupation, craft specialization, and the emergence of cities. First, the rise of the state includes the emergence of a group of people working together, with certain members in control of production and infrastructure, such as bureaucrats. The second trait, specialization in occupation, refers to the appearance of individuals that specialize in a particular skill, such as farmers, fishers, or potters. This specialization in occupation led to the third trait, which is craft specialization, where there was great development of crafts in different areas such as ceramics, textiles, and metals. These art forms were very specific for a variety of societies and helped to draw boundaries around groups. Finally, the emergence of cities occurred, gathering regionally-scattered populations in one settlement. The emergence of cities and its denomination as such is, however, controversial amongst researchers. Some prefer to define these settlements as administrative-religious centres, rather than cities (Makowski 2012, 2016). In varying degrees, the different societies of this period have these characteristics in common. The various societies that were present during the Early Intermediate Period and the transition to the Middle Horizon include: the Moche societies in the north coast, Cajamarca societies in the north highlands, Recuay society and Huarpa society in the central highlands, Lima society in the central coast, Topará and Nasca traditions on the south coast, and Tiwanaku in the Andean Plateau. The societies that had the most influence on the site of Cerro de Oro include the Lima and Nasca during the EIP, followed by the Wari during the MH.

1.2. Lima, Nasca and Wari: Cerro de Oro’s Neighbours

The crafts and styles that define various traditions within the Andes can be used to examine the horizontal and vertical connections among them, where each society often influences the other’s styles, ideas, and cosmology. Cerro de Oro is a great example of this conglomeration and exchange of ideas and expertise. There are two main traditions whose traits have been found represented in similar ways at Cerro de Oro. These societies include the Lima in the north and Nasca in the south, during the EIP. Influence from these traditions can be found within the iconography and ceramic styles at Cerro de Oro, as well as the style of burials, which is closely related to the Nieveria style from the Lima or Nasca (Fernandini 2018a, 2020). During the MH, some Wari burials intrude Cerro de Oro architecture. Therefore, to better understand the site of Cerro de Oro, and its connections with other societies during its period of occupation, it is important to examine these neighbouring societies.

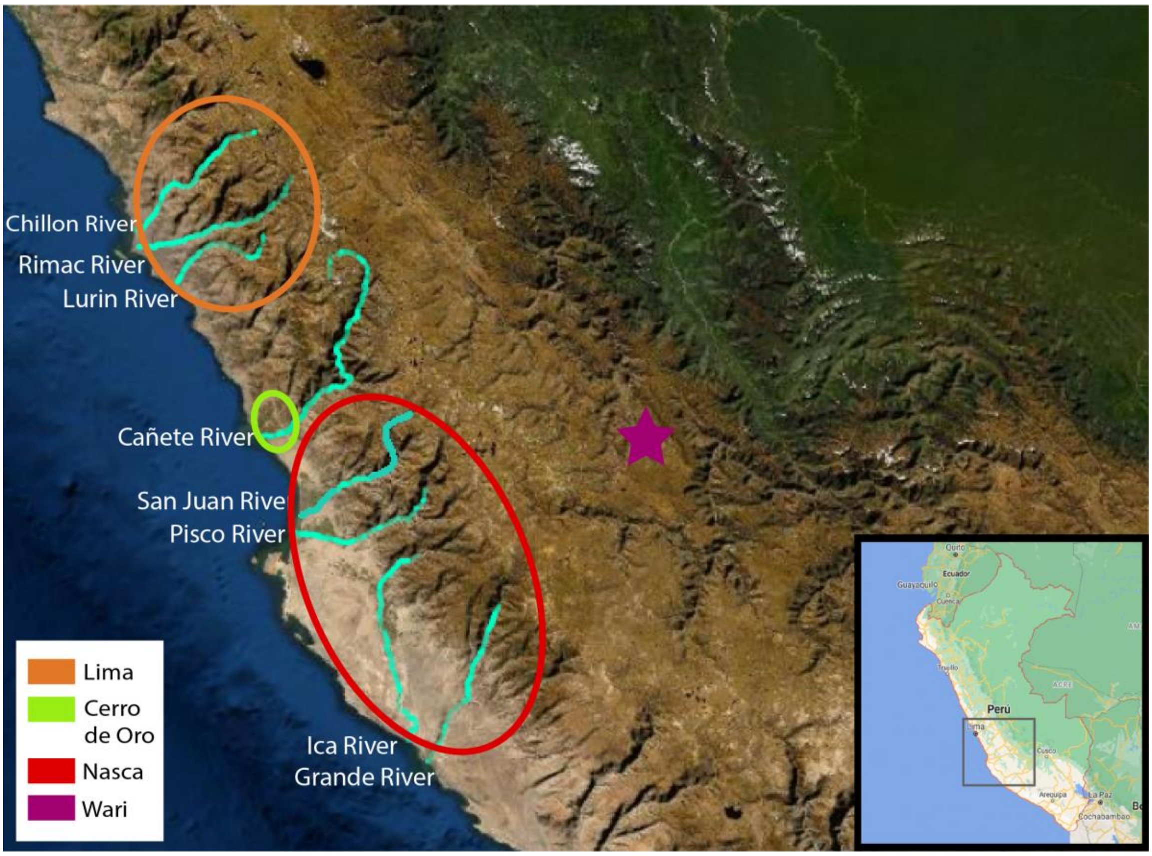

Figure 2.1. Lima, Cerro de Oro, Nasca societies influence areas and Wari epicentre

1.2.1. Lima

Lima tradition developed on the central coast between 200 CE and 750 CE, during the EIP to the Wari expansion. This society was located between Chancay in the north to the Lurín river in the south. Some Lima sites have, however, been found up to the Chillón, Rimac and Lurín middle valleys, in order to access the *chaupiyunga* ecosystem, which provided a different variety of crops and resources. Regarding the political organization of the Lima communities, it has been proposed that at the beginning, Lima society presented a tradition shared by several relatively independent groups, which by the end of the EIP, started a progressive centralization process and developed more rigid political organization(s) and a rearrangement of social structures (Marcone 2015). Researchers (Willey 1943; Kroeber 1954; Stümer 1954c; Lumbreras 1969, 2011; Earle 1974; MacNeish et al. 1975; Dillehay 1979; Shady 1982; Agurto 1984; Kaulicke 2000; Makowski 2001, 2002, 2012b, 2004; Marcone 20012 quoted in Makowski and Vallenas (2015)) agree in the later creation of a political body with the characteristics of a state or lordship (complex chiefdom), differing in its chronology, type of social relations, and modalities of power (Makowski and Vallenas 2015). Despite this debate, there is evidence of some kind of hierarchy within the society for the coordination and creation of public architecture such as irrigation networks, which expanded the amount of cultivable areas, and the construction of canals and reservoirs (Villacorta 2015). Lima also had its own artistic traditions that reflected its regional identity and was distinct from other cultural styles.

The Maranga Complex, located in the modern city of Lima consists of different monumental areas and around 20 mounds forming a huge metropolis (Lumbreras 2011). The growth and centralization of this site are linked with the creation and expansion of hydraulic networks, particularly irrigation channels (Villacorta 2015). This creation could be related to the climatic changes around 600 CE that brought drought to the coast (Mauricio 2018). Another important site within this tradition and period was Cajamarquilla. Located close to the old Huaycoloro River, it was a political-administrative and ceremonial centre. Communal agricultural work was organized from there, controlling the irrigation channels (Narváez 2006; Segura 2001).

Agriculture and fishing were the main economic activities for subsistence within the Lima society (Ikehara 2019; Villacorta 2015). However, there was also a great development of pottery and textile production, reflecting the growing regional identity of Lima society. The most representative styles would be the Interlocking, Maranga, and Nievería. The latter, coinciding with the end of the Lima society, incorporated iconography from the south coast and highlands, specifically Nasca and Wari (Marcone 2015). The Wari influence also arrived at Lima sites during the Middle Horizon, becoming Pachacamac in the Lurin Valley, the primary regional power in that period (Makowski and Vallenas 2015). After this period of Wari influence, some Lima society sites remained inhabited by the Ychma society during the Late Intermediate Period (Villacorta 2015).

1.2.2. Nasca

Nasca tradition developed mainly within the Grande River Basin in the Palpa and Nasca valleys, edging into the Ica and Pisco valleys to the north and Acarí to the south. It developed approximately between 50 CE and 650 CE. The Nasca emerged out of the Paracas tradition, after the disappearance of the Ocucaje tradition, differentiating from the northern Topará tradition (Makowski and Kołomański

2019). The area that the Nasca populated was within desert environments, however, these areas were located around rivers to create inland oases far from the coastline (Pardo and Fux 2017). Regarding its social and political organization, the Nasca organized around ceremonial centres controlled by different chiefdoms or Nasca groups. This organization led to the construction of irrigation architecture to widen the thin agricultural fields that were in the southern valleys (Mujica et al. 2015).

Cahuachi, located in the Nasca River Valley, was the main ceremonial centre. It was already inhabited during the Late Paracas and the transition between Paracas and Nasca (Pardo and Fux 2017). However, it was during the Early Nasca (50 CE – 300 CE), that it was occupied by a religious elite in charge of the political, economic, and religious aspects of Nasca society where there were also artisans dedicated to pottery and textile production (Mujica et al. 2015). From Cahuachi they controlled smaller regional centres in nearby valleys. The abandonment of Cahuachi and other centres was rapid. It has been suggested that this process of abandonment could have been related to climate change, specifically drought (Orefici 2016; Orefici 2009). After the abandonment of Cahuachi, the Nasca population reorganised and tended to occupy larger settlements out of the Grande River basin in search of more stable sources of water such as surface water and groundwater as infiltration galleries (Mujica et al. 2015; Reindel and Isla 2013). This led to the emergence of new elites and urban centres. There were also changes in the iconography and religious beliefs, elaborating new geoglyphs and widening others (Mujica et al. 2015). Hydraulic works became an important part of Nasca society, economy, and cosmology, the most representative examples being the *puquios*, which were part of a hydraulic system to obtain groundwater. This water was stored in lagoons or reservoirs (*qochas*) that shunted into canals. These *puquios* or eyes of water had spiral ramps to access groundwater and to maintain the network of canals. Most of the ritual and religious constructions such as geoglyphs and Nasca lines are linked with water, fertility cults, and associated rituals (Lasaponara et al. 2016; Mujica et al. 2015; Pardo and Fux 2017).

1.2.3. Wari

During the EIP, the Huarpa society developed in the modern-day Department of Ayacucho. After the EIP, throughout the Middle Horizon, there was a cultural expansion from this region towards the central and north coast and highlands, reaching Cajamarca in the north and Moquegua in the south. Huarpa was followed by the Wari tradition, an expansive state (Isbell 1985; Isbell and Schreiber 1978). The Wari have been considered the first Andean empire (Lumbreras 1980; Schreiber and Parsons 1992), however, there is a debate around the nature of the Wari's relationship with and conquest of the different groups and territories (Chirinos 2006; Makowski and Giersz 2016; Schreiber 2012). To control other regions that they had conquered, the Wari employed forms of political and military control, often depicted in various iconographic works (Rodríguez et al. 2015). Another way used by the Wari to control newly conquered areas was to form alliances with the local elites; these alliances would benefit the local communities through collaboration on various construction projects and connections with other groups (Makowski and Giersz 2016). Wari expansion was also supported by the absorption and syncretism of Wari iconography established during this period throughout much of the Andes (Makowski and Giersz 2016). The Wari phenomenon started around 550 CE and reached its zenith between 650 to 775 CE, collapsing between 1000 to 1100 CE (Rodríguez et al. 2015).

The site of Wari, located near the present-day city of Huamanga, was the capital of this empire. It was an urban centre of around 600 ha, with an architectural pattern replicated in the other provincial Wari centres such as Cerro Baúl (Williams et al. 2001; Williams 2001). There are some other planned centres with rectangular design such as Pikillacta (McEwan 2005), with the presence of elite burials in distant sites like Espiritu Pampa in Cusco Amazonia or Castillo de Huarmey in between the central and north coast; these reflect the expansionist character of Wari. Regarding Wari agriculture, the mountains provided scarce fields, high aridity, and little water. To combat this, the Wari developed a water cultivation system, which involved the creation of various hydraulic works to efficiently cultivate and store water from summer rains to be used throughout the year (Rodríguez et al. 2015). They also used wide cultivation terraces (platforms) and canal networks, previously used by the Huarpa (Segura Llanos 2019). Agriculture in the *Quechua* zone and maize consumption were extensive (Rodríguez et al. 2015).

1.3. Environment from the EIP to MH

Environmentally, the transition between the EIP and MH periods was marked by particularly strong El Niño Southern Oscillation (ENSO) events, especially around 600 CE (Mauricio 2018). This affected the kind of economy of the different groups who inhabited the Andes at that time. While the coast received intense rainfalls, often causing flooding, landslides, mudslides, and erosion, impacting human settlements and agricultural fields, the highlands were affected by droughts and floods during ENSO events ((CAF) 2000; Caviedes 1984; Mauricio 2014). This climate phenomenon decreases the intensity of trade winds causing an increase in sea surface temperature. These changes in the sea have serious consequences for thermosensitive marine species, causing them to die off or move south, being replaced by tropical or more ENSO-resistant species (Mauricio 2018).

A variety of evidence of El Niño havoc has been documented in EIP sites along the Peruvian Coast (Beresford-Jones et al. 2009; Dillehay 2001; Franco and Paredes 2000; Kaulicke 1993; Mogrovejo and Segura 2000). There is evidence of at least one ENSO event around 600 CE that affected almost the entire Peruvian coast. These events significantly influenced the social changes that happened during the EIP to MH transition (Mauricio 2018). This led some authors to directly link the ENSO with the abandonment of major coastal settlements and the fall of the main societies of the EIP during the seventh century (Moseley and Richardson 1992; Shimada et al. 1991). However, some settlements and agricultural fields were relocated to less susceptible areas in response to these changing environmental conditions, not only to avoid the impacts of El Niño, but also to take advantage of its benefits such as the formation of ephemeral lagoons, vegetation blooming, and groundwater recharge (Dillehay 2001). Despite the relocation of many sites, others remained occupied until at least 800 CE but experienced significant changes in their configuration; other important settlements were built and used between 600 and 800 CE (Mauricio 2018).

During the EIP-MH transition, which coincides with the main period of occupation at Cerro de Oro, their neighbouring societies, the Nasca and Lima, were experiencing severe droughts and other environmental changes. The fluctuations in environment had a direct impact on these populations, causing a variety of social transformations (Beresford-Jones 2011; Mauricio 2014; Mauricio 2018; Mujica et al. 2015).

In some parts of the Nasca region, erosion caused by floods led to the abandonment of alluvial terraces used as fields (Beresford-Jones et al. 2009). Clearance of the algarrobo (*Prosopis* sp.) forest to obtain more farmland was the beginning of the rapid desertification of this area, with this process ending in the terminal Middle Horizon (Beresford-Jones 2011; Beresford-Jones et al. 2009). Moreover, in this region, bioarchaeological and DNA studies suggest that coastal populations relocated towards the high parts of the valleys starting around 640 CE (Fehren-Schmitz et al. 2014). Based on ice core δ^{18}O records from the Quelccaya ice cap (Thompson Lonnie et al. 1984), the Ayacucho region in the highlands may have suffered a severe and prolonged drought during the sixth century (Glowacki and Malpass 2003). This drought could have led to the pursuit of more arable and fertile lands out from Ayacucho (Cook and Glowacki 2003). In contrast, Cerro de Oro's establishment seems to be related to the expansion of irrigation channels from the Cañete River to the site, facilitating extensive agriculture at this site (Fernandini 2018b). Environmental and climatic changes were likely the triggering event(s) to cause the development of irrigation at Cerro de Oro, as well as intensive agriculture to satisfy population expansion.

1.4. Agriculture during the EIP

The communities within the Central Andes relied on agriculture as their main source of economic activity during the EIP. Agriculture was rooted in a mixture of perennial (trees) and annual crop species, which required a long-term connection to a territory to annually harvest tree products and turn wild non-cultivated land into arable land through irrigation (Ikehara 2019; Kaulicke et al. 2019). Agricultural practices were strongly affected by water availability. Droughts and floods reconfigured not just the architectural and settlement landscape, but also the agricultural fields. During this period there was an expansion of the agricultural lands towards previously vacant land (Kaulicke et al. 2019:21). There was also an increase in the productivity of the land through artificial irrigation strategies as seen in the Lower Cañete valley (Fernandini 2018b). This led to the occupation of hitherto uninhabited sites for the development of agropastoral activities. The different adaptations to the great variety of environments in the central Andes played an important role in the regionalization processes that characterized the EIP (200 BC -550 AD). This period of agricultural intensification also saw an increase in the consumption of maize, both for domestic and ritual purposes (Ikehara 2019:197). Accordingly, obtaining a reliable source of water in an uncertain environment became crucial. In the Andean worldview, the economy was not extractive, but rather one that sought to exploit resources sustainably (Van Kessel 2003; Van Kessel and Condori Cruz 1992). Within these water management techniques are the systems of canals and ditches on the north and central coasts, the *puquios* and canals in south-central Peru, and the *quchas* or *cochas* in the high Andean areas, which are all varieties of water storage systems (Ikehara 2019).

Regarding the coastal region, artificial irrigation systems channel water from rivers in their mid-courses and distribute it to alluvial fans on the coastal plains. Humidity contributes to the formation of arable soil that remains for future generations (Ikehara 2019:162). Canals and irrigation systems on the coast were associated with the concentration of political power (Netherly 1964; Wittfogel 1956). It has also been pointed out that this type of infrastructure encourages the cooperation of multiple local communities (Kaulicke et al. 2019:21; Wilson 1987). No matter the driving force behind their construction, extensive and intensive agriculture were an important part of the formation of complex societies in the Andes (Ikehara

2019:163). Extensive and intensive agriculture will be addressed in more detail at chapter 5.

Cerro de Oro is no exception, as this site emerged with the aid of extensive agriculture and irrigation system construction probably linked with environmental adaptations. It has been proposed by Fernandini (2018b) that the congregation of people around this site could be due to two factors. First, the construction and expansion of irrigation canals brought water from the Cañete River to the site. Most of the current irrigation systems in the lower Cañete valley emerged around 600 CE, and the two channels that are still in use are the María Angola channel, formerly known as "Chumbe", and the San Miguel channel, previously called "Chiome or Chome". There were also other minor channels such as the "Guanca" and "Pachacamilla" channels, the "Sotoma" ditch, and the "Hualgará" and "Huancarca" aqueducts (Rostworowski 1989 [1977] 94). This canal system arose through a series of connections of the river to a series of small settlements and finally to Cerro de Oro. These other sites, closer to the river, were occupied during the EIP and were highly vulnerable to flooding, unlike Cerro de Oro. That is why, secondly, the floods caused by ENSO and the location of these earlier sites, together with the development of irrigation systems, could be the cause of the rise and growth of Cerro de Oro (Fernandini 2018b). Therefore, Fernandini (2018b) proposes that the floods caused by the mega-ENSO circa AD 600 and the location of these earlier sites, together with the development of irrigation systems, could have been the cause of the rise and growth of Cerro de Oro. The result would not be an emergency relocation, but a group of people building quickly, in an organised manner (Fernandini 2018b). The canal system that developed in the Lower Valley of Cañete, made most of the alluvial fan suitable for agriculture. The gradual expansion of the irrigation system occurred in conjunction with the gradual peopling of the valley (Figure 2.2). It happened in three phases, reaching Cerro de Oro during the last one (Fernandini 2018b).

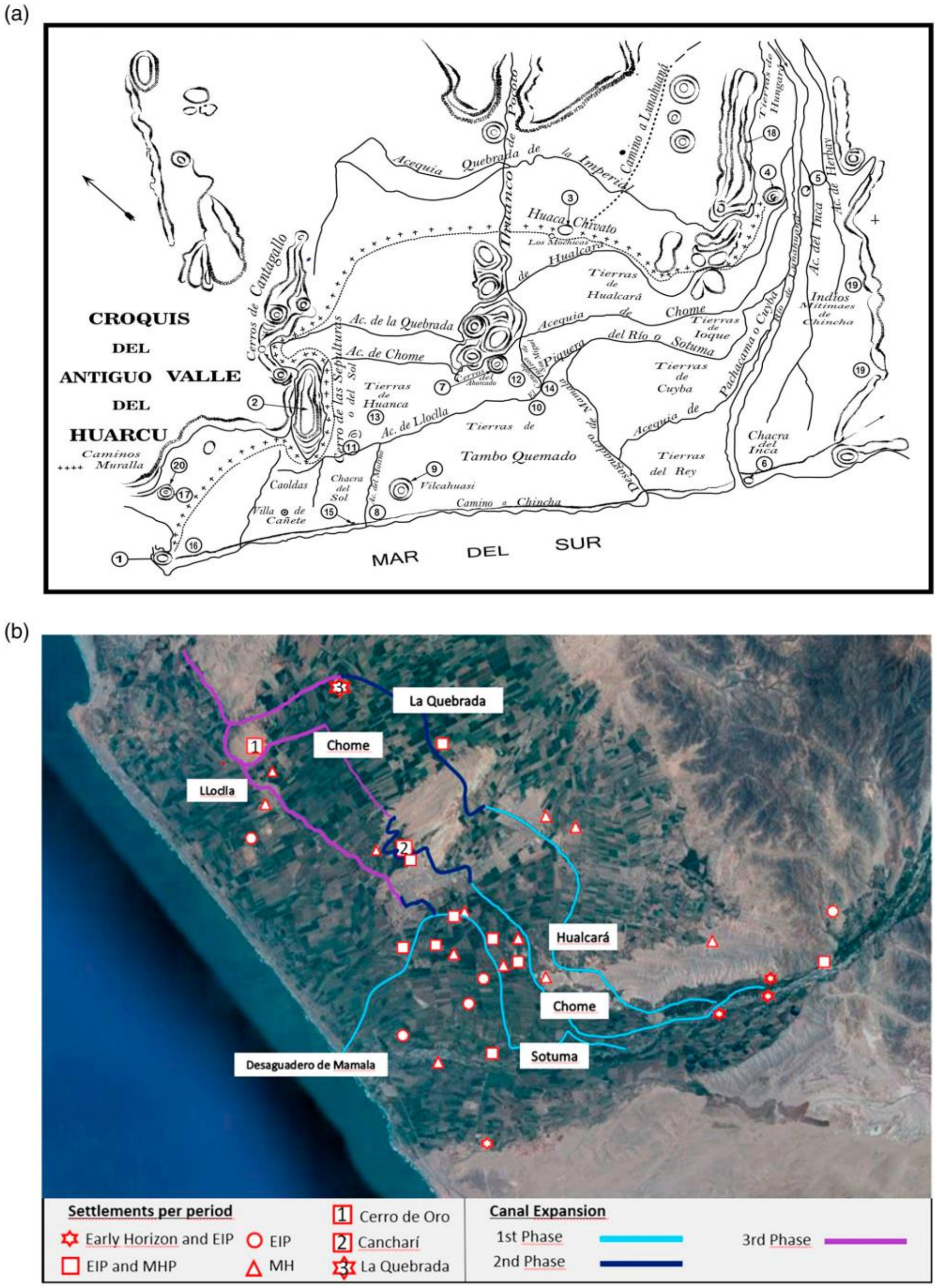

Figure 2.2. a) Larrabure y Unanue's 1935 map of the lower Cañete valley drawn in 1893. b) Map of the Cañete valley showing settlements per period and pre-Hispanic canals.

Source: (Fernandini 2018b)

Investment in infrastructure for water management and agricultural practices for the central and south coasts was described by the chronicler Cieza de León (1995 [1553])in *La Crónica del Perú.* He noticed that water cultivation was a common practice along the Peruvian coastline:

> *from the valley of Pachacama [...] up to that of Chilca, [...] water cannot be seen falling from the sky, nor does a river or stream pass through it, and most of the valley is full of fields of corn and other roots and fruit trees. [...] The water that the people of this valley drink is drawn from large and deep wells (Cieza de León 1995 [1553]; my translation).*

> Cieza de Leon went on to describe some of the agricultural practices such as irrigation and natural fertilization:

> *For their valleys to have the necessary humidity, the Indians make some wide and very deep holes, in which they sow and put* (their crops) *what I have said, and with the dew and humidity, it is God served that it grows, but corn by no means or The grain could not be born [...] if with each one they did not throw one or two heads of sardines from the ones they take with their nets in the sea, and so when they sow they put them and join them with the corn in their own hole that they make to throw the grains, and in this way, it is born and gives in abundance [...]. And in this place in the sea, they kill so many sardines, that it is enough to maintain these Indians and to make their crops with them (Cieza de León 1995 [1553]; my translation).*

He also described what the Cañete valley, named *El Guarco* at that moment, looked like:

> *The Guarco Valley (*Cañete*) is large and very wide and full of fruit groves. Especially there is in it a quantity of very fragrant and tasty guavas, and a greater number of pacaes. Wheat and corn grow well, and all the other things they plant, both natural and what they plant from the trees of Spain. [...] There are many pigeons, turtledoves, [...]turkeys, pheasants, some partridges and many deers. [...]. And the forests and thickets that make up the valley are very dark. Below them pass the ditches. In this valley, the inhabitants say that there was a large number of people in the past and that they competed with those from the mountains, and with other lords of the plains (Cieza de León 1995 [1553]; my translation)*

Finally, regarding the type of products grown on the Peruvian coast, Cieza de Léon describes some of the crops.

> *The Indians sow corn and harvest it twice a year, and it grows in abundance. And in some parts, they plant yucca roots, which are useful for making bread and concoction in the absence of corn, and many sweet potatoes are grown [...]. Also, there are some potatoes, many beans, and other tasty roots. Likewise, a large number of guava trees are born, and many pacaes, and avocados [...]. In many parts of these valleys, there are large numbers of cane fields of sweet cane, which is the reason that in some places sugar and other fruits are made with their honey (Cieza de León 1995 [1553]; my translation).*

1.5. Cerro de Oro: Early Research and First Insights

Figure 2.3. Geographical location of Cerro de Oro.

Source: Own imagen created from MyMaps (Digital Globe)

The archaeological site of Cerro de Oro has been investigated and excavated intermittently by different researchers since the beginning of the 20th century. The first investigations at the site were carried out by Dr. Julio C. Tello, who was also one of the first researchers to carry out work within the south coast of Peru, both at the site of Cerro de Oro in Cañete and at Huaca Malena in the valley of Asia (Villar-Córdova 1935). The results of his research performed in 1925 were published in *Revista Universitaria de Lima* (Tello 1925). The excavated materials were added to the collections of the Universidad Nacional Mayor de San Marcos and the national museums that Tello directed at that time (Daggett 2009:26). According to (Ángeles

2009:87), most of them are still there where Tello deposited them, in the National Museum of Archaeology, Anthropology and History of Peru. A review of this research has recently been completed (Padilla 2020).

In 1925, the anthropologist Alfred Kroeber also conducted research in the Cañete Valley, first at Cerro Azul and then at Cerro de Oro. The objective of his investigations was to increase the ethnographic collections for the Field Museum of Natural History of Chicago in the United States within the "First Marshall Field Archaeological Expedition to Peru". The material recovered is still in that museum. Kroeber's main contribution was his pioneering chronological and cultural differentiation at the site, creating a baseline for today’s refined and expanded chronologies and descriptions. Kroeber proposed a first differentiation of "cultures" or periods to which he assigns the names of Middle Cañete and Late Cañete (Kroeber 1937:228). He made this differentiation based on the funerary contexts that he excavated and their stylistic affiliations. Kroeber suggested that the Middle Cañete dated to between the end of the EIP and the beginning of the MH and for Late Cañete, from the Late Intermediate to the Late Horizon. The Middle Cañete was characterized by the cranial fronto-occipital modification, the funerary structures of small cubic handmade adobe bricks, and Nasca stylistic influences in ceramics and textiles. This period would occupy the entire surface of the site with terraced cemeteries (Kroeber 1937). While Late Cañete, also called Late Chincha by Kroeber for its stylistic similarity with southern groups, would be related to the traditions of the Ica and Nazca valleys of the Rio Grande. For this period, Kroeber defined a walled cemetery, in the southwest part of the site, that today remains looted and exposed. The burials are characterized by the lack of cranial modifications and the presence of green stains, probably as a result of the decomposition of copper or other metals on the skeletal remains (Kroeber 1937).

A few decades later, between 1957 and 1959, Louis Stumer carried out the archaeological project of the Peruvian Coast within the Universidad Nacional Mayor de San Marcos. They explored the coastal valleys, for the purpose of preserving archaeological sites and to correlate the cultural sequences of the northern, central, and southern regions (Stumer 1971:23). Regarding the Cañete valley research, he described Cerro de Oro as an "atypical site [...], with its numerous constructions and tombs of the Regional Florescence period and its intrusions in the Reigns and Confederations period." (Stumer 1971:25). Stumer also refuted Kroeber’s idea of Cerro de Oro as a necropolis, and claimed that it was more likely to be a place where "all kinds of archaeological remains of the site are found, such as buildings, tombs, dumps, ovens, etc." (Stumer 1971:25). He also noted that the presence of funerary architecture and burials in domestic spaces may have influenced Kroeber’s site identification of Cerro de Oro as a large cemetery. Stumer's main contribution was the location of the occupations in Cerro de Oro in specific intermediate periods, which allowed him to correlate the site with other traditions in the area. Finally, and regarding this chronological proposal, it should be noted that Stumer (1971:28-29) calls the Middle Cañete the Cerro de Oro Culture and the Late Cañete the Huayco Culture.

In 1958, Dwight Wallace (1963) carried out excavations in areas of garbage dumps, excavating two trenches at Cerro de Oro (Menzel 1964:158). Some time after this, in 1964, Dorothy Menzel published a work compiling and analyzing the studies developed so far, carrying out a stylistic analysis of the ceramics that allowed her to chronologically order the occupations. She described the site as "eclectic" (Menzel 1964:157) due to its influences: Nievería, Nasca, and Chakipampa.

In 1999 Mario Ruales resumed the research at this site for just one season directing the "Proyecto de Investigación Arqueológica Cerro de Oro" (PIACO). A year later he published the article "Investigations in Cerro de Oro, Cañete Valley" where he made a ceramic analysis of the artifacts found at the site (Ruales 2000). Later in 2001, he published the excavation report (Ruales 2001). The major contributions of Ruales were at the architectural and chronological levels. He carried out excavations in the upper part of the main terrace to study the architecture, but also in the area that Kroeber called "Quebrada Norte", to better understand the chronology and occupations of the site. Concerning the architecture, he identified three architectural phases with distinctive patterns. The first one would be the earliest on the site with the use of small adobe bricks. The second phase was characterized by rammed-earth architecture, especially in the central, higher part of the site. Finally, a very small and unknown phase with stone structures characterized the last phase, which dated much later than the previous ones (Ruales 2000:364-365). Regarding the chronology of the site, Ruales described very marked changes between the cultural patterns of the Early Intermediate and those of the Middle Horizon (Ruales 2000:396). In this sense, he pointed out the aforementioned changes in architecture, but also in ceramics. These changes were both in iconography, which "massively imports popular elements and designs for the time that arise both in the central highlands and on the southern coast" (Ruales 2000:396), as well as in the use of new pigments. In addition, Ruales proposed that there is a certain formal continuity in both periods and that the ceramics of the Middle Horizon contexts should also be called Cerro de Oro style, since it is a "Cañete style" (Ruales 2000:397). Finally, he found changes in the funerary patterns, becoming more complex and confirming the occupational continuity, finding "funerary contexts of the same period, attached to structures already abandoned and dismantled" (Ruales 2000:398). Ruales concluded that there are patterns typical of Cerro de Oro. Although these patterns were transformed and influenced by foreign elements, there is homogeneity and continuity in these local traditions that do not disappear, but "are moulded to the new ways of life that are managed during the first period of the Middle Horizon" (Ruales 2000:398).

1.6. Archaeological Project of Cerro de Oro

Since 2012 the Cerro de Oro Archaeological Project (PACO), directed by Dr. Francesca Fernandini has carried out both archaeological excavations and constructing infrastructure at the site to promote the social use of the site by the community. In the beginning, this project focused on studying the transition period, between the Early Intermediate and Middle Horizon. The main goals have been to study the political, social, and economic changes and continuities at the site and to understand what role Cerro de Oro played in the sociopolitical organization of the area including the Chilca, Mala, Asia and Cañete valleys (Fernandini 2013:6). More specifically, the project aims to understand the dynamics of occupation at the site, the interrelationship between different aspects of the daily life of the inhabitants, and the construction and abandonment of the settlement (850-900 CE). This research project has focused on the period between 500 and 900 CE, focusing on the evidence associated with the Cerro de Oro occupation, but also on the Wari intrusive constructions (Fernandini 2015a:27).

1.6.1. Cerro de Oro Sector Division

Fernandini, based on Kroeber (1937) and Ruales (2000, 2001), had first conducted aerial photography and a survey of the entire site and divided Cerro de Oro into five sectors (Figure 2.4) (Fernandini 2019:2-4).

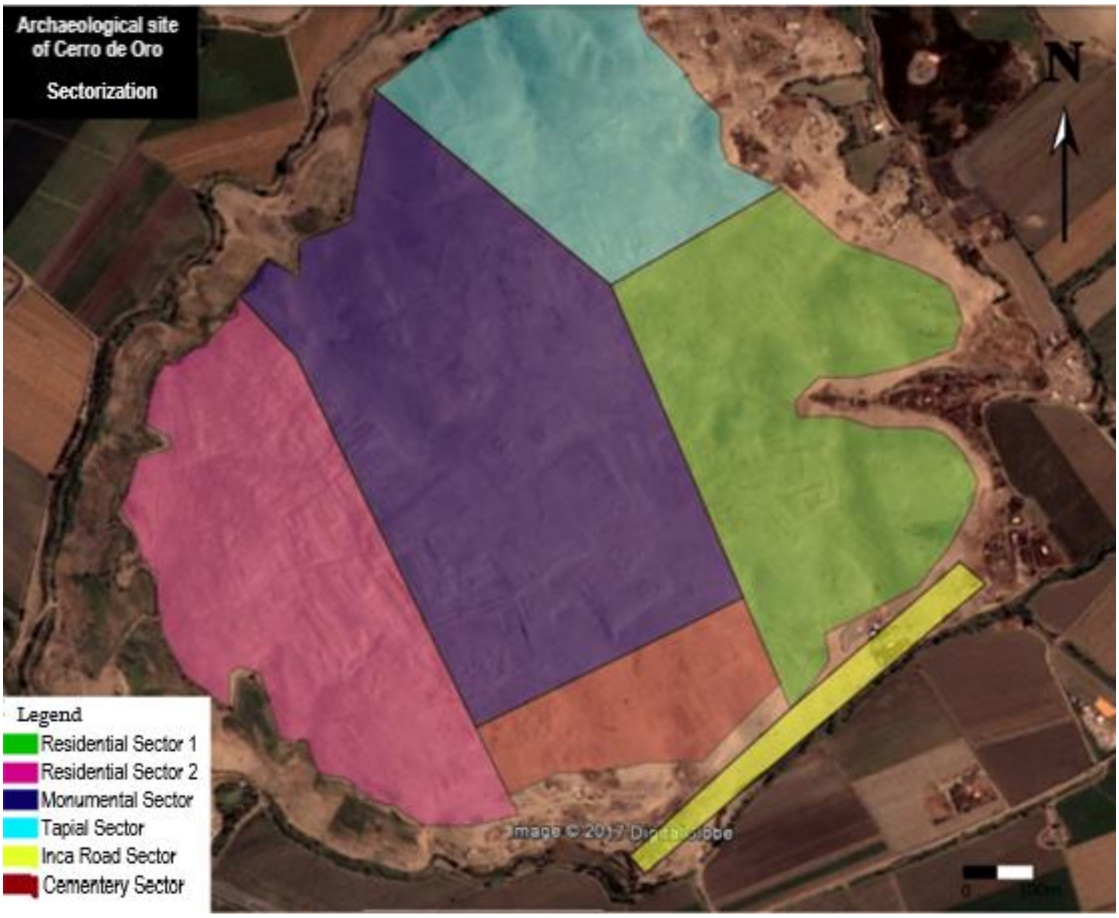

Figure 2.4. Sectors into which the archaeological site of Cerro de Oro is divided
Source: Own image created from MyMaps (Digital Globe)

- **Monumental Sector:** this sector is made up of a series of adobe structures with walls between 4 and 8 m in height, most of them being wide structures, with perimeter walls up to 200 m in length. The largest building within this sector is represented by a rectangular enclosure whose walls reach 8 m in height. This sector was excavated by PACO in 2015 (Fernandini 2016). It has been proposed that these monumental buildings were built around 600

CE, being used until 900 CE (associated with an occupation designated as Cerro de Oro). Subsequently, the internal surfaces and platforms of these buildings were used to place funerary bundles between approximately 1300-1500 CE, associated with the presence designated as Guarco-Inca.

- **Residential Sector:**
    - Residential Sector 1 is located to the SE of the site in a natural esplanade. This sector has been excavated by PACO in 2012, 2013, 2015, 2017 and 2019 (Fernandini 2013, 2014, 2016, 2018a). These excavations exposed the sequence of construction and division of space. This sector is characterized by at least 30 rectangular or semi-rectangular structures that present many internal divisions. Six of those rectangular structures have been excavated, all of which contained domestic areas. This sector has many spaces for food preparation, storage, kilns for ceramic production, small rooms where it is believed the inhabitants slept and, in general, evidence associated with the daily life of the inhabitants of Cerro de Oro. All the excavated elements are associated with the Cerro de Oro occupation, except for an intrusive tomb that has been associated with the Wari cultural tradition.

    - Residential sector 2 is located to the NW of the site, which is terraced. This sector was excavated by PACO in 2019 (Fernandini 2020). A part of a large platform was excavated, and the surrounding walls were defined. In this excavation, domestic structures, *quincha*, a very well-preserved platform, and a large number of adobe walls, some of them up to two meters high, were found. In addition, several formal combustion structures were found, built with adobes. Finally, the intrusion of a funerary context with Lima-influenced grave goods and four large vessels with Cerro de Oro style iconography were found. Obsidian tools were also found in this area of the site.

- **The Tapial Sector** is located in the northern area, at the highest part of the site over an artificial platform that was created by modifying the highest part of the hill to build an esplanade. It was investigated by PACO in 2015 (Fernandini 2016), defining three types of architecture: rectangular enclosures made of small cubic adobes linked to the first occupation called Cerro de Oro (550 - 900 CE), quadrangular or rectangular tapial enclosures associated with the Guarco-Inca period and structures that mix the use of tapial with carved stone and mortar, which later modify the tapial walls.

- **Inca Road Sector:** Located at the SE end of the site and framed by tapial walls. This road is identified in the map published by Larrabure y Unanue (1935) as the road that would be descending from the middle valley and crossing the entire valley nearby the archaeological site of La Quebrada.

- **Cemetery Sector:** Characterized by the presence of a large number of funerary structures and burials, generally in funerary bundles. Most of them are located within the Cerro de Oro architecture, although it is proposed that they may have belonged to the Guarco-Inca population. This is the sector most affected by looting, which has been systematic in this area since the abandonment of the site.

1.6.2. Cerro de Oro Periods of Occupation

Cerro de Oro presents a long period of occupation, over approximately 1000 years (ca. 500-1600 CE), varying in intensity through time. Fernandini confirmed and refined the proposal of Ruales (2000), finding continuity between the Early Intermediate and Middle Horizon contexts. This period was named as the Cerro de Oro Phase, "being characterized by a sequence of floors, ranging from bedrock to the present surface" (Fernandini and Ruales 2017:3). To this end, a series of stratigraphic analyses, ceramic seriation and radiocarbon dating were carried out (Fernandini 2015b:9). There appears to have been a temporary hiatus following the Cerro de Oro phase when the site was used superficially without significantly affecting the architectural landscape. Finally, between the Late Intermediate and Late Horizon, Cerro de Oro would have been inhabited by the Guarco-Inca society, who built using *tapial*, and reused the domestic structures built in adobes during previous times for the placement of burial bundles (Fernandini 2013:53).

1.6.2.1. Cerro de Oro Period (550 and 850 CE): From EIP to the MH

As discussed previously, the origins and the construction of this 150-ha monumental settlement were influenced by the effects of environmental changes, water availability, and food procurement (i.e., agricultural practices). There would be two main reasons for this accumulation of people at this site. First, the construction and expansion of the irrigation channels and canals that brought the water from the Cañete River. Most of the current irrigation system in the lower Cañete Valley may have been constructed circa 600 CE, related to the rise of a series of small settlements and finally with Cerro de Oro. Second, is the flooding that was likely caused by ENSO events. The construction and expansion of these canals are linked with some other Early Intermediate Period sites that would have been highly vulnerable to floods, unlike Cerro de Oro (Fernandini 2018b).

During this period there was great cultural development at the site with changes, continuities, and foreign influences, especially from the Lima and Nasca. These three traditions had "a local development without temporal hiatuses, but with multiple cultural changes up to the Middle Horizon 1" (Fernandini and Alexandrino 2016:39). Cerro de Oro is a clear example of cultural dynamism in which iconography responded on certain occasions to the synergy of iconographies from surrounding areas, which is characteristic of the late Early Intermediate Period and early Middle Horizon on the central coast. This is what Menzel (1964) refers to as the "eclectic" ceramic style. This hybridization at Cerro de Oro also later incorporated Wari elements. These continuous cultural processes broke with the temporal schemes of the Andean chronology elaborated on by, among others, Rowe (1962) and his students Dorothy Menzel and Lawrence Dawson (1964), without being able to be located strictly within the Early Intermediate or the Middle Horizon (Fernandini 2015b:12). Thus, Fernandini (2015b:13) proposed that this period of the late EIP and early MH should be used as a continuous cultural reference for this area. This period had constant construction and remodelling in the multiple residential complexes, including divisions, platforms, roads, and accesses. Fernandini has described a subdivision of this phase, based on the remodelling processes of the excavated areas, with up to five subphases (Fernandini 2014, 2018a, 2020). (Fernandini 2015b). The Cerro de Oro phase ends with the abandonment and closure of certain spaces around

850-900 CE with evidence of sealing processes of architectural spaces in various areas of the site. Radiocarbon dates for the site are presented in Appendix 1.

1.6.2.2. Wari Intrusive Period (ca. 900-1000 CE)

A Wari intrusive phase is documented during a short period of around 100 years after the abandonment of Cerro de Oro. This phase is characterized by the construction of intrusive rooms, some with elaborate walls with niches and accesses to the east, that were used as elite funerary contexts (Fernandini and Alexandrino 2016; Fernandini 2015b). This process is related to the strategic expansion of the nascent Wari empire, replicating its constructions (administrative centres and planned settlements) in other territories. The appearance of objects characteristic of Wari seems to conform to a pattern, which today gives the false impression of a homogeneous Wari presence (Fernandini 2015b:11). However, no evidence of a domestic Wari occupation has been documented, so according to (Fernandini 2015a:44), these funerary contexts could have been built by a local population, possibly in direct contact with Wari representatives. Therefore, this intrusion would be a momentary, rather than a prolonged, occupation at the site (Fernandini 2015a:58). Conversely, some Wari stylistic concepts were incorporated at Cerro de Oro, syncretizing with previous foreign elements. The Wari presence at Cerro de Oro is due more to an indirect process materialized through copies, emulations, and hybridizations, than to the expansion of the Wari political organization. This is key to understanding the development of local identity processes on the south-central coast and particularly at Cerro de Oro (Fernandini and Alexandrino 2016:41). These patterns of abandonment of sites occupied during the Early Intermediate and subsequent intrusive funerary reuse are recurrent during this Late Middle Horizon period for the central and south-central coast. According to Fernandini (2015a:44), this would reflect an intention to create a prestigious and hybrid identity.

1.6.2.3. Guarco-Inca Period, (1100-1500 CE)

This phase is directly related to the neighbouring site of Cerro Azul. This occupation occurs between the Late Intermediate Period and the Late Horizon, mainly characterized by tapial architecture, located mostly in the highest part of the site, but also in other lower sectors, excavated by PACO in 2018. In addition, it is associated with intrusive funerary contexts in the lower areas of the settlement. This rammed-earth architecture generally has a short duration, and the space is often later reused. In addition, the constructions located at the top of the site have been separated from the rest of the settlement by a dividing stone wall (Fernandini 2015a:58).

1.6.2.4. Fourth Period

The last occupation is the least studied and is associated with a highland occupation, possibly by neighbouring populations to whom the Incas ceded land (Rostworowski 2005). There are no dates for this last occupation, but it consists of intruding rammed earth walls and in some areas adobe, so it seems to be the latest recorded at the site.

In summary, Cerro de Oro emerged as a political centre that influenced neighbouring centres. Cerro de Oro is thought to have been led by a dominant group that directed, managed, and planned the expansion of the site and increased ceramic production during the period between the Early Intermediate and the Middle Horizon (Fernandini and Ruales 2017:6-7).

1.7. Ongoing Research at Cerro de Oro by PACO

After answering some of the initial questions about chronology and architecture, PACO has branched its efforts into other fields and in this way, it has investigated how "objects are produced or obtained, used, altered, discarded, reused and, in general terms, inserted into material practices" (Fernandini 2015a:2). In this sense, it is worth mentioning the research conducted by Rosa María Varillas (2016), who thanks to the excellent preservation of organic materials offered by the Cerro de Oro site, conducted both an iconographic and technological study of the textiles found at the site (Varillas 2016:3). Subsequently, Carol Rodriguez performed a formal and decorative analysis to assess the impact of foreign influence on the local production of ceramics (Rodríguez 2017:26), focusing mainly on the Cerro de Oro bowl, this being a characteristic form of the Cerro de Oro site in its first phase. On the other hand, the relationship of the inhabitants with the site they inhabit has been further studied from their funerary practices. To this end, Gabriela De la Puente-León (2018) conducted an analysis of funerary contexts in domestic spaces and the extremely important social role played by death in the lives of its inhabitants. Finally, a multidisciplinary study about commensality and diet was performed by González Gómez de Agüero (2019) including zooarchaeological, malacological, micro- and macrobotanical, and ethnographic analyses, specifically examining the prevalence of birds and camelid consumption at the site. The high presence of guanay (*Phalacrocorax bougainvillii*) and peruvian booby (*Sula variegata*) in the archaeological record indicate not just their consumption but also the presence of guano reservoirs near the site. This research demonstrated the presence of a great number of fish taxa and the importance of agriculture in the diet at Cerro de Oro with more than 20 different plant taxa.

1.8. Isotopic Studies in the Andes

This section briefly summarizes some of the themes in stable isotope studies conducted in Andean archaeology. More detail is provided on how stable isotopes vary in Andean environments and in plants in particular in the next chapter. In comparison to the richness of the archaeological record, relatively few, but significant, isotopic studies have been conducted on archaeological material from the central Andes. Although the pace of research in this area is accelerating, isotopic compositions of foodstuffs (i.e., stable isotope food webs or baselines) found in the archaeological record are still scarce in most areas. Specifically, in the area that concerns this study, the coastal resources of Peru have not been isotopically defined in the literature (Cadwallader 2012). This is why, for faunal isotopic baselines, researchers tend to use the studies of Tieszen and Chapman (1992) conducted on modern material from Arica, and northern Chile more generally, that present the isotopic signatures of marine resources such as fish, invertebrates, marine birds and mammals, and also some plants. Other studies that provide some isotopic data related to Peru include the study by DeNiro and Hastorf (1985), which presents the carbon and nitrogen isotope ratios of some modern and ancient Peruvian plants, as well as studies on the north (Szpak et al. 2012a, 2012b, 2013; Szpak and Chiou 2020) and south coasts (Cadwallader 2012; Cadwallader et al. 2012). Other studies have complemented the baselines usually used in Andean stable isotope research, providing small numbers of relevant marine and terrestrial animal isotopic data (Schoeninger and DeNiro 1984). Even so, more and more isotope studies are helping to better understand not only what people ate, but also how their diet and the exploitation of the environment they inhabited influenced their relationships and definitions of collective identity. In this sense, we can highlight the contributions made for the south coast (Cadwallader 2012; Cadwallader et al. 2012; Horn et al. 2009; Hundman 2016; Kellner and Schoeninger 2008; Knudson et al. 2007; Knudson et al. 2015; Scaffidi et al. 2017; Thornton et al. 2011; Tomczak 2003; Webb et al. 2013), the central coast (Coutts et al. 2011; Gerdau-Radonić et al. 2015; Marsteller et al. 2017; Marsteller 2015; Slovak and Paytan 2011; Tykot et al. 2006; Williams and Anne Katzenberg 2012) and the north coast (Bethard J.D. et al. 2008; Knudson et al. 2017; Lambert et al. 2012; Szpak et al. 2012a, 2012b, 2013, 2020; Szpak and Chiou 2020; Szpak and Valenzuela 2020; Vásquez et al. 2018; Verano and DeNiro 1993; White et al. 2009). In addition, this type of analysis has also been developed in the highland zone (Finucane et al. 2006; Finucane 2007; Somerville et al. 2015; Takigami et al. 2021; Tung and Knudson 2018; Turner et al. 2010), where there are also studies on the isotopic signature of lacustrine resources (Miller et al. 2010). These studies have, however, been limited in their ability to interpret the relative importance of specific dietary resources because of the lack of appropriate baseline isotopic compositions for the foods that may have been consumed. This is particularly problematic in a region that contains both C_3 and C_4 plants, marine resources, and fertilizers that may cause terrestrial resources to appear isotopically indistinguishable from marine resources (Szpak et al. 2012b). Additionally, as explored in greater detail in Chapter 3, isotopic analyses of plant remains themselves can provide important insight into agricultural practices (Fiorentino et al. 2015). While these techniques have been applied widely in Europe and to some extent Asia and the near East, only two studies with methodological foci (both of which employed a very limited sample size) have been conducted in the Andes (DeNiro and Hastorf 1985; Szpak and Chiou 2020).

3. Stable Isotope Analysis

Isotopes can be defined as forms of the same element that differ in the number of neutrons in the nucleus, meaning there are differences in their atomic mass (Fry 2006). Stable isotopes, such as carbon-13 and carbon-12, do not undergo decay, as radioactive isotopes such as carbon-14 do, and the structure of their nuclei does not change over time. Stable isotopes are found in different proportions within living beings. Those differences are caused by physical and chemical reactions that fractionate isotopes at the atomic level (Fry 2006). This produces characteristic changes that can be tracked and occurs because the lighter isotope reacts more rapidly than the heavier isotope (Hoefs 2015; Sharp 2017). These reactions can be caused by chemical, biological, or geological processes, as well as anthropogenic factors. For the lighter elements, relative abundances of stable isotopes are expressed as a ratio of heavy to light isotopes multiplied by 100, relative to an international reference standard (Fry 2006):

$$\delta^{H}X = [(R_{sample}/R_{standard}) - 1]$$

δ notation is the nomenclature and is reported in parts per thousand (per mil, ‰). X would be an element and H is the heavy isotope of that element, while R represents the ratio of heavy to light isotopes in the sample or the standard respectively (Fry 2006). For example:

$$\delta^{15}N = [(^{15}N/^{14}N_{sample} / {}^{15}N/^{14}N_{standard}) - 1]$$

In biological systems, these small differences in the distribution of heavy and light isotopes caused by fractionation reflect ecological and environmental conditions. This means that environmental changes affecting a plant or food resource can be tracked in an organism’s tissue isotopic values. Furthermore, stable isotope analysis (SIA) can trace natural and human processes in archaeological contexts (Lee-Thorp 2008). There are several processes that occur in the biosphere that lead to characteristic patterns of isotopic variation at multiple scales (West et al. 2010). These are mainly related to plant-soil systems, with the largest fractionations being produced by plants and bacteria, which directly affect the isotopic compositions of those that consume them or rely on the nutrients they produce. The study of plant isotopic compositions in an archaeological context is important, not just to reconstruct ecological and human processes, but also to understand animal and human dietary patterns.

3.1. Plants Stable Isotope Analysis in Archaeology

Since the early 1980s, SIA has become an important tool for the reconstruction of the diet and ecology of human and animal species in archaeological and paleontological contexts (Szpak 2014). To develop a complete reconstruction of human diet and environment in the past, it is important to understand which processes could affect plants, animals, and therefore humans, in the food chain. SIA of plant tissues has many different applications within archaeology. SIA in archaeobotanical research allows for paleoenvironmental reconstruction (e.g., foraging ecology of extinct species and large-scale shifts in ecosystems due to natural and anthropogenic processes), palaeodietary reconstruction, agricultural practices, or the assessment of the geographic origins of foodstuffs (Fiorentino et al. 2015; Szpak

2014). However, isotopic analysis of macrobotanical remains has been limited, especially within the central Andean region. Diet reconstructions usually rely on research conducted by DeNiro and Hastorf (1985) and Tieszen and Chapman (1992), which provide baseline plant isotopic compositions for modern taxa from the Atacama desert, which has a unique environment that is different to most other areas in South America or archaeological plants from the southern highlands of Peru. The variability in plant δ^{13}C and δ^{15}N for any particular region is not likely captured by either of these studies and therefore interpretations of human stable isotope values from other regions with these baselines may be biased and inaccurate. Therefore, it is very important for archaeological research in the Central Andean region to create regionally- and temporally-specific isotopic baselines.

SIA of archaeological plants has explored topics mostly related to agricultural practices, especially the use of fertilizers (Bogaard et al. 2007; Szpak and Chiou 2020) and more generally, creating isotopic baselines of possible consumable plants for ancient human populations (Aguilera et al. 2008; Alagich et al. 2018; Araus et al. 2014; Bogaard et al. 2018; Styring et al. 2017; Vaiglova et al. 2014). Building on this research, studies using archaeobotanical remains have created estimations of past water inputs (Araus and Buxo 1993; Araus et al. 1997a; Araus et al. 1997b; Araus et al. 1999a) and crop yield (Araus et al. 1999b; Araus et al. 2003a) using quantitative models in wheat and barley through the analysis of δ^{13}C.

Regarding the analysis of δ^{15}N, the work of Bogaard et al. (2007) first drew the attention of archaeologists to the impact of fertilizers on the isotopic compositions of plants and the animals and humans that consume them. Studies on soil fertility (Aguilera et al. 2008; Araus et al. 2007) and crop manuring in archaeological contexts have been developed in the last two decades mostly using material from

European archaeological contexts (Bogaard et al. 2007; Bogaard et al. 2016; Bogaard et al. 2013b; Fraser et al. 2011; Gröcke et al. 2020; Larsson et al. 2019; Styring et al. 2016; Styring et al. 2016; Styring et al. 2018; Styring et al. 2016; Vaiglova et al. 2014). Only a few studies have addressed intensive crop manuring in Andean Archaeology using isotopic evidence (Santana-Sagredo et al. 2021; Szpak and Chiou 2020).

3.2. Carbon Isotopes: Sources of Variability

During photosynthesis, plants preferentially take in ^{12}C relative to ^{13}C, meaning there is discrimination against the heavy isotope (Fiorentino et al. 2015). This process is affected by different environmental conditions and physiological mechanisms among plants that have implications for their carbon isotopic compositions.

3.2.1. Photosynthetic pathway and taxonomy

The photosynthetic pathway is the main factor influencing carbon isotopic composition ($\delta^{13}C$) of terrestrial plants. We can differentiate among C_3, C_4 and CAM plants. C_3 plants fix carbon through the Calvin cycle. Fractionation occurs mainly in two steps during diffusion of CO_2 through stomata, and during carbon fixation by the enzyme RuBisCO, the latter causing the biggest source of discrimination within the plant (Fiorentino et al. 2015). C_3 plants are characterized by lower $\delta^{13}C$ values (ca. −26 ‰) than C_4 plants (ca. −12 ‰) (O'Leary 1981; Smith and Epstein 1971), due to C_3 plants discriminating more strongly against the heavier isotope (^{13}C) than C_4 plants (Szpak et al. 2013). C_3 plants represent ~90% of the vascular plant taxa in the world, with most crops using this photosynthetic pathway (Raghavendra 2003), including all tree species, legumes, and cereals such as wheat and barley. Most of the plants in this study are of the C_3 variety, with more than 30 different taxa including edible and inedible (e.g., cotton, *Gossypium barbadense*) crops. C_4 pathway plants use the Hatch-Slack pathway to fix carbon. Most of them are tropical grasses, with the most important in New World archaeological contexts being maize (*Zea mays*), but also amaranth (*Amaranthus caudatus*). Maize is the only C_4 plant in this study sample, being the most abundant botanical remain at the Cerro de Oro and probably the most commonly consumed by people at the site based on the abundance of botanical remains (González Gómez de Agüero 2019). CAM pathway (Crassulacean acid metabolism) plants fix carbon in a similar way to C_3 plants overnight, but utilize a mechanism that is somewhat analogous to C_4 photosynthetic pathway during the afternoon (O'Leary 1988). CAM plants tend to have carbon isotopic compositions that are intermediate between C_3 and C_4 plants. CAM plants typically live in desert environments and include many cacti and related species. No CAM plants were analysed as part of this study.

3.2.2. Environmental and Vegetative Factors Affecting Plant $\delta^{13}C$

There are a variety of different environmental factors that can influence the carbon isotopic composition of plant tissues. They are ultimately the product of changes in photosynthetic conditions (i.e., the conditions under which stomata are open vs. closed) but are correlated with geographic location and different ecological parameters. Some of these environmental factors include irradiance (i.e., light availability in different parts of the plant could cause different $\delta^{13}C$ values with higher irradiance causing leaves to have less negative $\delta^{13}C$ values) (Ehleringer et al. 1986; Zimmerman and Ehleringer 1990), canopy effect (i.e., low-growing plants in dense forest tend to have lower $\delta^{13}C$ values than more open environments because of the recycling of CO_2 at the forest floor) (van der Merwe and Medina 1991; Vogel 1978), soil salinity (i.e., saline conditions initiate stomatal closure, therefore reducing the discrimination against ^{13}C by the plant (Farquhar et al. 1989), and altitude (i.e., foliar δ^{13}C values increase with increasing altitude, although the reasons behind this pattern are still unknown; (Vitousek et al. 1990). However, the environmental factor that is more likely to affect plant δ^{13}C in plants at Cerro de Oro is water availability. There is a relationship between the carbon isotope value of plants and the amount of water available through environmental variables such as precipitation, relative humidity, and potential evapotranspiration within the plant (Araus et al. 2003b; Condon et al. 1993). For example, C_3 plants growing with low water input, will have higher δ^{13}C values than plants that are intensively irrigated (Lajtha and Getz 1993; Styring et al. 2017). When plants receive a steady supply of water, the stomata tend to remain open, allowing an essentially unlimited flow of CO_2 into the leaf, resulting in maximal discrimination against ^{13}C and therefore low δ^{13}C values within plant tissues. On the other hand, when plants are exposed to environmental stress like drought, the contrary happens in the stomata, increasing discrimination because CO_2 trapped within the plant cell while stomata are closed becomes progressively enriched in ^{13}C (Fiorentino et al. 2015). The result is higher δ^{13}C values when plants are water- stressed (Farquhar et al. 1982; Farquhar and Richards 1984). This relationship allows for the study of water status and irrigation practices in archaeological crop remains (Araus et al. 1997b; Bogaard et al. 2013b; Fiorentino et al. 2015; Jones et al. 2021). In arid zones with low rainfall, measurements of the Δ^{13}C (discrimination, which is calculated directly from the measured δ^{13}C value of the plant tissue) in plant tissues can work as a proxy of irrigation practices (Styring et al. 2017).

Finally, there are other physiological factors that affect variation in plant δ^{13}C. First, there is systematic intraplant variation in plant tissue δ^{13}C. While C_3 plants show variation in δ^{13}C values of leaves, stems, roots, and other tissues, C_4 plants often show little variation (Hobbie and Werner 2004). Photosynthetic tissues (i.e., leaves) tend to have δ^{13}C values that are 1 to 2 ‰ lower than non-photosynthetic tissues (i.e., woody stems and roots) in C_3 plants (Badeck et al. 2005). This is relevant for this research as different plant tissues from the same taxon were analysed. Also, temporal variation can affect plant δ^{13}C, with emerging leaves having higher δ^{13}C values than fully emerged or photosynthetic leaves (Leavitt and Long 1982).

3.3. Nitrogen Isotopes: Sources of Variability

Nitrogen is actively taken up by plants from the soil in most cases. The two most important nitrogenous sources utilized by plants are nitrate ($\mathrm{NO_3^-}$) and ammonium ($\mathrm{NH_4^+}$) (Szpak et al. 2013). Usually, nitrate is the main form of mineralized nitrogen available to plants, however, in some cases, such as waterlogged or acidic soils, ammonium may be predominantly used (Pilbeam 2010; Yoneyama et al. 2003). On the other hand, some plants intake atmospheric nitrogen (N_2) by symbiotic bacteria (rhizobia) that reside in root nodules (Vitousek et al. 2002). Plants can also take up nitrogen from organics (e.g., free amino acids) within the soil, although this has predominantly been observed in tundra environments (Persson and Näsholm 2001). The nitrogen isotopic composition of plants is therefore related to which of these nitrogen sources they utilize, and the fractionations associated within the nitrogen cycle (e.g., ammonification, nitrification, denitrification). Beyond the different kinds of nitrogen sources, the nitrogen isotopic values of plants, animals, and humans can also change due to environmental and anthropogenic factors.

3.3.1. Environmental Sources of Variability

3.3.1.1. Taxonomic variation and mycorrhizal association

For this research, eight of the taxa analyzed were legumes (Fabaceae), N_2-fixing plants that rely on atmospheric N_2. The $\delta^{15}N$ of atmospheric N_2 is ~0 ‰ (Mariotti 1983) and little fractionation of ^{15}N happens during the uptake and assimilation of N_2 by leguminous plants. Therefore, legumes tend to have low $\delta^{15}N$ values, typically ~0%. Legumes tend to have lower $\delta^{15}N$ values compared to non-leguminous plants. While some researchers proposed that legumes are minimally affected by manuring relative to non- legumes (Bogaard et al. 2013a; Fraser et al. 2011), experimental studies have shown that large enrichments in plant tissue ^{15}N can occur with manuring (Szpak et al. 2014).

Another important source of $\delta^{15}N$ variability is mycorrhizal (fungal) associations. Some plants have a relatively limited ability to directly assimilate soil nitrogen. Those plants develop a mutualistic relationship with mycorrhizae in plant roots providing plants with N, as well as other nutrients; in exchange mycorrhizae receive energy from plant photosynthates (Hobbie and Högberg 2012). Plants with these associations tend to have low $\delta^{15}N$ values compared to those with no fungal associations, as ^{15}N fractionation occurs during the transfer of N from fungi to plants (Hobbie et al. 1999). These effects vary according to the mycorrhizal type as well as local environmental conditions (Szpak 2014; Szpak et al. 2013).

3.3.1.2. Intraplant and temporal variation in plant $\delta^{15}N$

There are three main reasons that plants exhibit intraplant and temporal variation in their tissue $\delta^{15}N$ values. First, plants that rely on NO_3^- may have higher $\delta^{15}N$ values in the shoots relative to the roots. NO_3^- may be assimilated in either the root or the shoot, but it is always taken up by the roots. When NO_3^- is moved from the roots to the shoots to be assimilated, it has already undergone fractionation, leaving the residual NO_3^- pool relatively enriched in ^{15}N (Evans et al. 1996). Second, the movement of nitrogenous compounds between nitrogen sources and sinks is a source of intraplant variation in $\delta^{15}N$. During plant growth, N accumulates in certain tissues, moving from leaves and stems (nitrogen sources) to other parts of the plant, such as fruits, grains, or flowers (nitrogen sinks). The lighter isotope is preferentially mobilized to these nitrogen sinks and this can result in a difference in $\delta^{15}N$ between sources and sinks (Crawford et al. 1982) The leaves and stems of a plant are typically more enriched in ^{15}N compared to seeds and grains (Szpak et al. 2012a, 2012b).

The last major source of $\delta^{15}N$ variation for plants is the reliance on isotopically variable N sources as tissues form over time, which may be tied to the use of fertilizers in agricultural systems. The amount of N available to plants from fertilizers changes over time, and plants may therefore incorporate N with different nitrogen isotope compositions as the release of mineralized N from organic fertilizers (i.e., manures) is often associated with fractionation (Szpak et al. 2014). Knowing the possible type of fertilizer that was used and the approximate range of $\delta^{15}N$ values that it may have had is important for understanding fertilization in archaeological contexts. For Cerro de Oro, camelid dung, fish carcasses and seabird guano are the most probable fertilizers available to inhabitants of the site. As explained in more detail below, there are differences in the $\delta^{15}N$ values of plants that have been fertilized with these different manures.

3.3.1.3. Environmental Factors Affecting Plant δ^{15}N

As explained at the beginning of this chapter, environmental variation in plant δ^{15}N is often passed on to consumers (Ambrose and DeNiro 1986), including humans (Schwarcz et al 1999). Environmental variation in δ^{15}N is primarily affected by the openness of the nitrogen cycle, where the amount of precipitation, water availability, and temperature can change how much ^{15}N is retained in that environment (Handley et al. 1999). Warm and arid ecosystems are more susceptible to N loss through denitrification and ammonium volatilization, processes that leave the residual soil N highly enriched in ^{15}N (Handley et al. 1999). Numerous studies have found a negative correlation between plant δ^{15}N values and annual precipitation and/or water availability (Amundson et al. 2003; Craine et al. 2009; Handley et al. 1999). Therefore, plants growing in arid ecosystems would have higher δ^{15}N values than those growing in wet zones. Mean annual temperature (MAT) is also correlated with plant δ^{15}N values. Warmer ecosystems are characterized by higher δ^{15}N values than colder ecosystems (Amundson et al. 2003). While the environment at Cerro de Oro is warm and arid, agricultural practices, especially irrigation, could be mitigating the expected increase in δ^{15}N in hot, dry environments. Szpak et al. (2012b) observed δ^{15}N values in field-grown maize from the north coast of Peru that were not especially high. These authors attributed this pattern to the irrigation waters that were provided to the plants.

3.3.2. Anthropogenic Sources of Variability

Different agricultural practices can affect δ^{15}N values in plants. One of the most significant sources of variability is the use of fertilizers. Fertilizers are often applied to agricultural soils as a source of nutrients. Nitrogen is the most significant nutrient added to the soil via animal manure and the N isotopic composition of animal manure is often higher than that of endogenous soil N (Szpak 2014). The application of fertilizers derived from animal excreta in crops leads to an enrichment of ^{15}N in plants and soils. This occurs due to the preferential loss of ^{14}N during the volatilization of ammonium and the loss of N_2 via denitrification, leaving residual nitrogen enriched in ^{15}N (Mizutani et al. 1986). Therefore, plants growing in fertilized soils will have higher δ^{15}N values than those that were not fertilized (Bogaard et al. 2007; Fraser et al. 2011; Szpak et al. 2012a, 2012b). The δ^{15}N values in fertilized crops are differently affected depending on the type of fertilizer applied, the amount applied, and the duration of application. Different types of fertilizers have different δ^{15}N values and contain variable types of nitrogen that may be more or less prone to fractionation. For example, the manures that are mostly solid waste from terrestrial herbivores such as camelid dung typically have δ^{15}N values between 2 and 8 ‰ (Bateman and Kelly 2007). It is important to keep in mind, however, that if terrestrial herbivores had diets with very high δ^{15}N values as might be expected in arid environments or from the consumption of fertilized plants, the δ^{15}N values of their dung would also be higher. Slurry fertilizers (mixture of urine and dung) tend to have higher δ^{15}N values, often between 6 and 15 ‰ (Choi et al. 2002). Composting may also increase the δ^{15}N values of terrestrial animal manures (Choi et al. 2017). Seabird guano has the highest δ^{15}N values for animal fertilizers (20-40 ‰). It mainly consists of uric acid and is subject to significant NH_4^+ volatilization (Szpak 2012a, 2012b). Finally, animal carcasses such as, fish waste, can also increase the δ^{15}N values of plants growing with it (Ben-David et al. 1998; Gröcke et al. 2020). The most probable fertilizers used in Cerro de Oro were: camelid manure (based on the presence of corrals and the abundance of camelid remains at the site), seabird guano (based on the abundance of guano bird remains at the site and the proximity to guano deposits), and fish carcasses (based on the abundance of fish remains at the site). Variation in plant δ^{15}N values could be reflecting the use of different fertilizers and/or variable amounts of the same fertilizer. Previous isotopic studies of macrobotanical remains from Europe have made fairly precise claims about the type and amount of fertilizer that was applied to crops in the past, using expected ranges of δ^{15}N values for no manure, low manure, and high manure based on modern field studies (e.g., Bogaard 2013a). These kinds of semi-quantitative interpretations are not possible at Cerro de Oro and other sites in the Andean region. Interpretations of fertilization are based on a single isotope tracer (δ^{15}N). If there were three possible sources of fertilizer at Cerro de Oro, each of which had a different δ^{15}N value (e.g., camelid dung = +12 ‰, fish carcasses = +15 ‰, seabird guano = +25 ‰), it would be impossible to know the relative contributions of each fertilizer because there are too many unknowns in the resulting mixing equation (Schwarcz 1991). Since the specific δ^{15}N values of the different fertilizers are also unknown, the difficult in making quantitative interpretations related to fertilization is further compounded. Accordingly, crop δ^{15}N values must be interpreted in a more relative (i.e., comparisons among taxa or sites) and qualitative (relatively high, relatively low) manner, especially in the absence of comparative data from other sites in the region.

Some other agricultural practices (besides manuring) can also lead to variability in crop δ^{15}N values. For example, swiddening (slash-and-burn or shifting cultivation) consists of clearing vegetation by burning it to increase soil fertility. When the soil fertility declines, this land is left fallow for some years to regenerate after burning the remaining vegetation (Szpak 2014). During this process, the resulting charred organic material permits the retention of soil nutrients and the ashes enrich the soil in P and mineral nutrients such as K, Ca, Mg), while C and N are largely lost due to volatilization (Juo and Manu 1996). Soil mineralized N pools (NH_4^+ especially) increase significantly after burning. The duration and intensity of the fire will affect the organic material that is produced where low temperature fires result in charred organic materials (i.e., charcoal), rather than ashes and more fractionation, and in turn, more ^{15}N enrichment (Saito et al. 2007).

All these practices affect crops but also plant consumers. In agricultural societies where animals are fed with agricultural by-products it is possible that domestic animals, usually herbivores (e.g., camelids), have relatively high tissue $\delta^{15}N$ values. If these animals are foddered with plant parts such as leaves and stems that are typically enriched in ^{15}N relative to grains (Szpak 2014), their tissues may possess even higher $\delta^{15}N$ values. Even if animals are not provisioned with fodder, allowing them to graze on agricultural fields after the harvest may contribute fertilizer to the fields, a practice that has been observed in the Andes (McCorkle 1987). The integration of animal and crop management systems may therefore lead to relatively high $\delta^{15}N$ values overall.

3.4. Some Methodological Challenges: Desiccated vs Charred Plant Remains

Isotopic analyses of plant remains are usually performed on charred materials because they are more likely to preserve in the archaeological record, especially in European archaeological contexts where this type of research has been employed. Stable isotope measurements of charred botanical remains are widely accepted to be reliable, reflecting the isotopic composition of living plants after accounting for small offsets due to charring (Fraser et al. 2013; Nitsch 2015). After the pioneering work of DeNiro and Hastorf (1985), $\delta^{15}N$ values, and, in some cases $\delta^{13}C$ values in desiccated (uncharred) plant remains have been largely ignored because they have been assumed to be unreliable. They found that charred plants produced stable carbon (δ^{13}C) and nitrogen (δ^{15}N) isotopic compositions comparable to those of modern plants. Moreover, they found that desiccated plants produced δ^{15}N values that were often unusually high, typically between +10 and +20 ‰ and as high as +46 ‰. They could not find the specific mechanism causing the patterns in δ^{15}N, but some kind of post-burial alteration of the organic matter was suspected. This led to the assumption that only charred archaeobotanical remains were suitable for isotopic analyses.

As outlined by Szpak and Chiou (2020), there are three main problems with DeNiro and Hastorf's study. First, all of the desiccated remains in the DeNiro and Hastorf (1985) study came from low altitude sites on the arid coast of Peru, whereas the charred remains were collected from high altitude, inland sites. The plants grown within the coastal deserts of Peru are likely to have higher δ^{15}N values than the inland sites because of the hyper-arid conditions on the coast (Austin and Vitousek 1998; Handley et al. 1999; Szpak et al. 2013). Another explanation for the high δ^{15}N of the coastal plants is the use of seabird guano as fertilizer, which was extensively used in the past along the Peruvian and Chilean coasts (Curatola 1997; Julien 1985; Santana-Sagredo et al. 2021; Szpak et al. 2013). Lastly, the chemical pretreatments used in the DeNiro and Hastorf study were extremely harsh and may have resulted in isotopic fractionation of the plant material. Therefore, the pattern observed by DeNiro and Hastorf (1985) may not reflect diagenetic alteration of the isotopic composition of the desiccated plant remains (Szpak and Chiou 2020). To assess the reliability of the stable isotope values of desiccated remains, Szpak and Chiou (2020) carried out analyses on both kinds of samples from the Peruvian north coast, finding no differences in δ^{15}N or C:N between charred and desiccated remains. This study suggests that in addition to charred plant remains, desiccated plant remains can produce isotopic measurements that reflect the original isotopic compositions of living plants.

Regarding this study sample, around 6% of the samples were charred, and most of these charred samples were maize cobs. The rest of the samples are desiccated remains. To further investigate the reliability of the stable isotope values of the desiccated remains, the δ^{15}N values of the charred and desiccated remains were compared, using a large sample size for a single taxon (maize), addressing a shortcoming of Szpak and Chiou's (2020) study.

4. Materials and Methods

4.1. Materials

A total of 31 plant taxa were analysed for this research project, all of which were collected from the archaeological site of Cerro de Oro. The total number of samples was 529, however some of the plants used within this study were subsampled, bringing the total number of samples analysed to 571. Subsampling occurred mainly for plants that included a variety of tissues (e.g., maize cobs with grains still attached). Through this subsampling, comparisons between different tissues within some plant taxa was possible. Most of the plant taxa examined were C_3 plants and legumes, with maize being the only C_4 plant included. The environmental conditions of growth, nutritional value, and economic importance will be explained below for each of the plant taxa analysed in this study. The number of samples analyzed for each taxon is also summarized in the text below.

4.1.1. ***Arachis hypogaea*:** Its common name is peanut and *maní* or *cacahuete* in Spanish and it is grown as an annual herbaceous plant that belongs to the Fabaceae family. Like most other legumes, peanuts harbour symbiotic nitrogen-fixing bacteria in their root nodules. This legume is rich in fats and proteins that increase when roasted. Its fruits are usually eaten, but its seeds and leaves can also be eaten in a green or germinated state. Peanuts can be consumed raw, roasted, cooked, candied, or crushed. It can be conserved by smoking it, which, in addition, increases its protein content (León 2013:180-183). Another form of consumption of peanuts is peanut *chicha* that is still consumed today in areas of the Middle and Lower Cañete valley.

Samples analysed in this study: 20 pods (Figure 4.1) and 1 seed

Figure 4.1. *Arachis hypogaea* pod recovered from Cerro de Oro

4.1.2. *Baccharis* sp.: Its common name is *chilco* and it is a shrub from the family of the Asteraceae that grows near *Gynerium sagittatum.* Its common use was to provide a green and yellow dye for cotton garments. It also has medicinal properties, and its wood is used in construction and as firewood (Fernández and Rodríguez 2007). It could also be consumed (León 2013).

Samples analysed in this study: 1 stem

4.1.3. *Bunchosia armeniaca*: Its common names are c*iruela del fraile o cansaboca*. This small tree is a species in the Malpighiaceae family and is native to tropical America. It grows in the Amazon and develops well in the inter-Andean valleys and along the coast (Fernández and Rodríguez 2007). Its fruits are rich in carbohydrates, calcium, phosphorus, and vitamin C. In addition, this tree produces good firewood (León 2013:273).

Samples analysed in this study: 1 seed.

4.1.4. *Caesalpinia spinosa*: Its common name is *tara*. Wild or cultivated, it grows in the *lomas* and on the coast, reaching up to 3000 m.a.s.l. (Fernández and Rodríguez 2007). Its pods are rich in tannins (50-60%) and the infusion of its fruits is used to help sore throats, mouth infections, and sinusitis. In addition, it has astringent, disinfectant, antidiarrheal, and anti-inflammatory properties. It was also used as a dye (Fernández and Rodríguez 2007).

<u>Samples analysed in this study:</u> 1 pod

4.1.5. *Canna indica*: Its common name is *achira* and it is a perennial herbaceous plant. This plant can be found within Peru along the coast and the inter-Andean valleys, up to 2,000 m.a.s.l. It has an edible rhizome that can be consumed boiled or baked. It could be cooked in "*huatia*" ovens, for a dish that is know as *pachamanca* today (Gade 1966). It has a large amount of starch, can be eaten raw or cooked, and is easily digestible (León 2013:77).

<u>Samples analysed in this study:</u> 7 rhizomes, 5 leaves and 1 stem.

4.1.6. *Canavalia* sp.: Its common name is *pallar de los gentiles*. This genus includes 40 species, of which 12 can be found within Peru. It is a legume that adapts to adverse climates, dry soils, and the infestation of insects, unlike, for example, common beans. *Pallar de los gentiles* grows from a twining plant that can reach up to 1 metre. They are rich in calcium and phosphorus and are often found within iconographic depictions in Mochica ceramics and Paracas textiles (Fernández and Rodríguez 2007).

Samples analysed in this study: 30 seeds and 1 pod. One sample was subsampled, containing one seed and the pod to the same individual.

***4.1.7. Capsicum* sp.:** Its common name is chilli pepper and *ají* or *rocoto* in Spanish. They are herbaceous or shrubby plants with a woody trunk that is branched. This genus in the central Andes region includes *Capsicum baccatum, Capsicum pubescens* and *Capsicum frutescens.* Its characteristic spicy flavour is the product of capsaicin, which also favours the production of endorphins. In addition, it stimulates the appetite, boosts the immune system, and helps fight against rheumatoid arthritis and fibromyalgia. The yellow pepper has nutrients with analgesic and anti-inflammatory properties (León and Chávez Cornejo 2019:170-178).

Samples analysed in this study: 6 peduncles, 3 stems, 1 seed and 1 fruit.

4.1.8. *Cucurbita* sp. Its common names are squash, pumpkin and *zapallo*, or *calabaza* in Spanish. This genus includes *Cucurbita maxima, Cucurbita fictifolia* and *Cucurbita moschata,* which are the common varieties within the Peruvian archaeological record. They are adaptable annual plants that are easily cultivated, needing moderate soil moisture. Almost all parts of the plant are consumed, from its fruits to its seeds, flowers, shoots, and leaves. In pre-Hispanic times, they were probably consumed raw, toasted, or fried, and the seeds could be dehydrated and dried for storage. In addition, its pulp could be used as a detergent (León 2013:240-244; León and Chávez Cornejo 2019:829-830).

Samples analysed in this study: *Cucurbita* sp: 4 seeds and 3 peduncles

4.1.9. ***Cucurbita maxima*:**

Some of the cucurbit remains found at Cerro de Oro have been identified as *Cucurbita maxima*. They contain a large amount of water, carbohydrates, minerals, and vitamins (León 2013; León and Chávez Cornejo 2019).

Samples analysed in this study: *Cucurbita maxima:* 29 seeds, 11 peduncles and 1 stem

4.1.10. ***Cyperus* sp.:**

Its common name is rush and *junco* in Spanish. These graminiforms are mostly rhizomatic, usually growing in wet and swampy areas (Fernández and Rodríguez 2007). These plants were often used in the construction of mats, rafts, baskets, and fans in the coastal pre-Hispanic societies. Its rhizomes may have been consumed during pre-Hispanic times (León 2013).

Samples analysed in this study: 11 plaited ropes (Figure 4.2) and 6 fibers.

Figure 4.2. *Cyperus sp. plaited rope* recovered at Cerro de Oro

4.1.11. *Equisetum intectum*: Its common name is horsetail and *cola de caballo* in Spanish. It is a hydrophilic plant that usually lives in wetlands. Nowadays, it can be seen growing on the edges of the irrigation canals in the Cañete valley, and along the edge of the Cañete River. It can also be used as a diuretic (León 2013:512).

Samples analysed in this study: 2 stems

4.1.12. *Erythroxylum coca*: Its common name is c*oca* and is a small bush that grows between 500 and 2000 masl, although it can adapt to a variety of environments, including warm/humid and acidic soils (Fernández and Rodríguez 2007). This plant is consumed as a stimulant, where the dried leaves are chewed, generally adding an alkaline paste (*llipta* or ash). Only cultivated species contain enough alkaloids to be *chacchados* or chewed and be used as stimulants, since these alkaloids improve the metabolism of starches, which provides an increase in energy and reduction of fatigue. The funerary context found in the 2019 PACO excavation season contained two small bags, one with coca leaves and the other with ash. In addition, seeds of this plant have been found at Cerro de Oro.

Samples analysed in this study: 2 seeds

4.1.13. *Furcraea andina*: Its common name is *cabuya or penca* and is a giant weed in the Asparagaceae family. It grows in the Andean region up to 3000 m.a.s.l., and is used to make twine, ropes, sacks, carpets, and ornaments. To extract the fibers, the leaves are left to macerate in water for several days, then the leaves are hit on a support (wood or rock), the soft tissue is detached, leaving only the fiber. It is then dried to obtain the fiber strands (Fernández and Rodríguez 2007).

Samples analysed in this study: 1 fiber

4.1.14. *Gossypium barbadense*: Its common name is cotton and *algodón* in Spanish and it is a perennial plant. Cotton had a very important role in the economic and social development of coastal communities. It was the most commonly used fiber throughout the entire occupation of Cerro de Oro, being around 80% during the Cerro de Oro phase (Varillas 2016). Cotton fluff found at the site was usually whitish, dark, or light brown in colour. However, it has been found dyed in a large range of colours. It was used mostly for clothing and everyday items such as cords, fishing nets and even *quipus*. Other ritual objects such as cloth bundles or hats found in funerary contexts are usually made with camelid fiber and sometimes with a mixture of camelid and cotton fibers. For the manufacture of textiles, other vegetable fibers such as cabuya (*Furcracea andina*) and camelid wool were also used (Varillas 2016).

Samples analysed in this study: 4 boll cortex, 3 bracts, 8 fibers, 14 seeds, 1 stem.

4.1.15. *Gynerium sagittatum*: Its common name is wildcane and c*aña brava* in Spanish. It is a tall grass that inhabits the margins of coastal rivers forming the cañabravales or riverside mountains, up to 1,500 m.a.s.l. Its main use was for the construction of walls and roofs. It was also used to make mats and baskets (Fernández and Rodríguez 2007). It had medicinal uses, but there is no evidence of this plant being eaten (León 2013).

Samples analysed in this study: 8 stems

4.1.16. *Inga feuilleei*: Its common names are *pacae, pacay*, or *guaba* and it is a tree that grows from the coast to the 3000 masl. The fruit that grows from this tree is a part of the legume family, meaning that the tree is a nitrogen- fixer (National Reserach Council (U.S.) (1989)). It is rich in sugars, water, and vitamins, making it a good source of energy. It also contains calcium, phosphorus and is a good source of polyunsaturated fatty acids, in particular omega-3 and omega-6 (León and Chávez Cornejo 2019:633). It acts as a shade tree and can also help other crops grow by increasing long-term soil fertility through nitrogen fixation (Fernández and Rodríguez 2007).

Samples analysed in this study: 17 seeds and 9 pods.

4.1.17. *Ipomoea batatas*: Its common name is sweet potato and *camote, batata* or *boniato* in Spanish. It is a perennial herbaceous plant that produces an edible tuberous root (Figure 4.3) that is high in starch. It produces more biomass and nutrients per hectare than any other crop (León 2013:85), contains antioxidants, helps prevent cardiovascular diseases, and even controls diabetes (León and Chávez Cornejo 2019).

Samples analysed in this study: 2 tuberous roots.

Figure 4.3. Desiccated sweet potato found at Cerro de Oro

4.1.18. *Lagenaria siceraria*: Its common name is calabash or bottle gourd and *mate* in Spanish. It is an annual herbaceous plant very resistant to pests and insects and belongs to the Cucurbitaceae family. Its dried fruits are mainly used to make containers for liquids and food. The remains in Cerro de Oro correspond to exocarp fragments that were part of these containers. However, their consumption as food cannot be ruled out before they matured when they were still green (León 2013:239).

<u>Samples analysed in this study:</u> 9 exocarps and 2 seeds

4.1.19. *Manihot esculenta*: Its common name is cassava, manioc, *yuca* or *mandioca* in Spanish. It is a perennial shrub of 2 to 3 m tall and has a tuberous root that is rich in starch and is therefore a great source of energy. There are more than five thousand varieties of this species. However, cassava varieties are commonly designated as "bitter" (poisonous) and "sweet" (non-poisonous). The ways to eliminate this toxicity is by inducing its fermentation and releasing the volatile cyanide gas, which can then allow for the plant to be used in making flour, drying it in the sun or boiling it (León 2013:97; León and Chávez Cornejo 2019:814-821). It can be eaten raw, parboiled, roasted, fried or cooked, but also in flour, bread preparations, and sweets. In addition, it is used to prepare alcoholic beverages such as *masato* and *tapiaco*. Its leaves are edible and can be cooked like spinach, allowing it to be a good source of fiber and protein that increases if cooked (León and Chávez Cornejo 2019:814-821).

Samples analysed in this study: 2 stems and 1 tuber

4.1.20. *Persea americana*: Its common name is avocado and *palta* or *aguacate* in Spanish. This tree reaches heights of 20 m in its wild state. The avocado tree can be grown from sea level to 2,500 m.a.s.l., and its fruit is an edible berry that is rich in fats (12.5% of its fruit), which are highly digestible, and contains a variety of minerals such as iron and vitamins A and B (León 2013:256-258) The fruit has numerous health benefits, including preventing the development of arthritis, helps skin regeneration, has laxative, antioxidant, antibacterial, and antiviral properties, and prevents anemia. The leaves also have some health benefits, specifically that they are hepatoprotective. The custom of eating it with salt or sugar could have arisen during colonial times (León and Chávez Cornejo 2019).

Samples analysed in this study: 5 seeds

4.1.21. *Phaseolus lunatus*: Its common name is lima bean and *pallar* in Spanish. This perennial plant is a legume that is high in protein and can be eaten as dehydrated seeds, as sprouts, green leaves, and pods. In addition, its cooking times, as with the *Canavalia sp.* are long, to eliminate its toxic cyanine content (León and Chávez Cornejo 2019:645-648). The lima bean is often depicted in Moche and Nasca iconography, as well as at Cerro de Oro. Images of *Pallar Vaquita*, an anthropomorphic bean has also been found in Cerro de Oro iconography (Figure 4.4). The pod sample was subsampled to analyse both the pod and the seed contained within. The *Pallar Vaquita* was subsampled to analysed both white and black parts separately.

Samples analysed in this study: 39 seeds and 1 pod.

Figure 4.4. Vessel with anthropomorphized *pallar vaquita* seeds and *pallar vaquita* seeds found at Cerro de Oro.

4.1.22. *Phaseolus vulgaris*: Its common name is bean, *frejol, frijol* or *poroto* in Spanish. This legume is an annual plant, from 2 to 3 meters high, and the roots have bacterial nodules. Bacteria that live in parenchymal cells receive carbohydrates from the plant and supply it with nitrogen (Fernández and

Rodríguez 2007). They are rich in calories (between 300 and 350 per 100 g), protein, calcium, and iron. They may help to prevent several chronic and degenerative diseases, such as cardiovascular disease, obesity, and diabetes. Its peel contains a large amount of fiber and this helps regulate cholesterol. The dried seeds of the beans are an excellent diuretic and are also used against anemia and malnutrition. Regarding their preparation and consumption, they reduce their values in most minerals, vitamins, and ashes when they are washed, cooked, and increase their potassium, fiber and some amino acids when they are fermented (León and Chávez Cornejo 2019:393). Many different varieties of beans have been found at Cerro de Oro. Analysed pods have been subsampled to analyse both the pod and the bean contained within.

Samples analysed in this study: 37 seeds and 15 pods

4.1.23. *Phaseolus vulgaris* Sub. *Nunas*: Its common name is popping beans, *ñuña*, or *frejol reventón* in Spanish. It is a type of the common bean (*Phaseolus vulgaris*) and is native to the Andean zone (Figure 4.5). This plant is harvested after 5-9 months, and is found above 2,500 meters, from Ecuador to Peru. This legume bursts when cooked, being heated with a little oil in a similar way to *cancha serrana* or popcorn. It is calorically dense, having 338 Kcal per 100 g, and is rich in protein and fiber (Fernández and Rodríguez 2007).

Samples analysed in this study: 18 seeds.

Figure 4.5. Different legumes found at Cerro de Oro. From left to right: *ñuña*, *pallar negro* (both in the middle) and *pallar de los gentiles*.

4.1.24. ***Pouteria lucuma*****:** Its common name is *lúcuma*. It is a perennial tree that grows to a height of between 10 and 20 m. It is a source of carbohydrates as it is rich in starch and calories (León 2013). This tree can also provide various health benefits where it can be used as an anti-inflammatory, antioxidant, antihypertensive, antibacterial and stimulant (Maza-De la Quintana and Paucar-Menacho 2020). Its wood is also fine and compact and is highly valued in carpentry and for its heating properties (Fernández and Rodríguez 2007).

Samples analysed in this study: 30 seed cortex, 6 inner seed, 9 leaves, 2 fruits pulp and 1 fruit rind. Some seeds were subsample where x.1 is the cortex or shell of the seed and the x.2 is the inner, woody, hard part of the seed. Figure 4.6 shows the two parts of this kind of seed. Fruits were subsample separating the epicarp, mesocarp and seeds when possible.

Figure 4.6. *Pouteria lucuma* seed found at Cerro de Oro. Notice the inner woody hard part and the cortex or shell of the seed.

4.1.25. ***Prosopis pallida*:** Its common name is carob tree and *algarrobo* (north of Peru) or *Huarango* (south of Peru) in Spanish. It is native to the north coast of Peru and it is distributed from sea level to 1,900 m.a.s.l. usually occupying the arid, semi-arid dunes of the Peruvian coast. It is a tree from the Fabaceae family, meaning that its fruits are legumes (Fernández and Rodríguez 2007). Its pods and seeds are sweet and rich in sugars, and the seeds are rich in carbohydrates, proteins, and fiber, as well as vitamins E and C. It also has medicinal properties, including extracting its leaves and bark for mouth and throat infections, ulcers, bronchitis, and general pain and parasites. It is used to make desserts and fermented drinks such as carob (León and Chávez Cornejo 2019). Its consumption has been recorded into recent decades on the Peruvian north coast and even in Ica (Bonavia 1982). In addition, its wood is good for firewood and for construction.

Samples analysed in this study: 2 pods

4.1.26. *Psidium guajava:* Its common name is guava and *guayaba* in Spanish. It was probably the most commonly eaten fruit in pre-Hispanic Peru (León and Chávez Cornejo 2019:428-434) as it produces fruits throughout the whole year (Hastorf 1999). It is a small tree that grows from 3 to 10 m, and its fruit has a lot of vitamin C.

Samples analysed in this study: 10 fruit pulps, 7 branches, 5 seeds, 2 peduncles and 1 stem. Fruits were subsampled where x.1 is the epicarp and mesocarp and x.2 are the seeds.

4.1.27. *Salix humboldtiana*: Its common name is *sauce* or *sauce criollo*. It is a deciduous tree that can measure up to 25 m and grows in humid places such as the banks of rivers. The bark of this plant has tannins, which are extracted by simple boiling and are used for leather tanning. A yellow to green dye is extracted from the bark and leaves, which is used to dye cotton. In some rural areas of Cañete, the leaves are used, crushing them to form a paste that is applied to the skin to heal wounds. In other coastal areas, the bark is used as an infusion to relieve fever and inflammation in general. It is also used as a purgative (León 2013).

Samples analysed in this study: 3 stems, 1 branch and 1 capsule

4.1.28. *Sapindus saponaria*: Its common name is *boliche, choloque,* or *tingana*. It is a small tree with fruits that contain saponin, which gives it the ability to produce foam, being used to make soap (Fernández and Rodríguez 2007). Its bark is used as an astringent and its external application is given for general healing, anti-inflammatory and anti-hemorrhagic.

Samples analysed in this study: 3 seeds

4.1.29. *Schinus molle*: Its common name is Peruvian pepper and *molle* in Spanish. It is a leafy woody arborescent evergreen tree that lives preferentially on the edges of ditches and rivers. Its fruits are used to prepare *chicha de mole* that is an alcoholic beverage, and its seeds are used as a substitute for pepper. Its resin was used by the Inca to embalm their corpses, and the bark and leaves were used to stain textiles a pale yellow. The wood is red and hard and is used in cabinetmaking (Fernández and Rodríguez 2007). In Cerro de Oro, these trees have been found to have been used as posts for construction. The components of its different parts have antioxidant, diuretic, antiseptic, antibacterial, antispasmodic, anti-inflammatory and healing properties. In addition, the infusion of its bark is used to treat diarrhea, and its resin is a powerful purgative and digestive regulator. Other health benefit of this plant include its use as an antidepressant, through the regulation of serotonin, dopamine, and epinephrine. It can be rubbed against the skin to be used as an insecticide against insects causing Chagas disease (León and Chávez Cornejo 2019).

Samples analysed in this study: 9 stems and 1 bark

4.1.30. *Typha angustifolia:* Its common name are narrowleaf cattail, lesser bulrush, and *totora* in Spanish. It is a perennial herbaceous rhizomatous plant that in Peru, grows in the valleys of the coast and the mountains, within ditches, puddles, or small shallow lagoons. These plants serve as food and shelter for numerous aquatic birds, and as a resource to create mats, baskets, and ropes. Its rhizomes are edible (Fernández and Rodríguez 2007).

Samples analysed in this study: 8 stems and 4 flowers

4.1.31. Zea mays: Its common name is maize and *maíz* in Spanish. Maize is the most common C_4 plant in the Andean archaeological record. This plant adapted to almost every ecosystem in the Andes. It is by far the most widely found edible botanical remain at Cerro de Oro, where several varieties of maize have been found, with different sizes and colours, although they have not been identified. It was the main source of carbohydrates at the site, based on the amount of plant remains found. The manner in which it was consumed varies among differenct maize cultivars: it can be eaten green, dehydrated, toasted (*cancha*) or boiled (León 2013; León and Chávez Cornejo 2019). Fermented beverages such as *chicha* can also be prepared. The increased consumption of carbohydrates such as maize and other plants rich in starches and other sugars has been linked to the increase in dental caries (Hillson 1996).

Samples analysed in this study: 84 cobs, 17 grains, 8 bracts, 7 stems, 4 flowers and 2 roots

Figure 4.7. Maize cob founded at Cerro de Oro.

The number of samples for each of the different taxa are summarized below in Table 4.1.

Table 4.1. Summary of the analysed samples

Taxonomic Name	**Common name**	**Type of plant**	**n**
Arachis hypogaea	Peanut	Legume	21
Baccharis sp.	Chilco	C_3	1
Bunchosia armeniaca	Ciruela del fraile or cansaboca	C_3	1
Caesalpinia spinosa	Tara	Legume	1
Canna indica	Achira	C_3	13
Cannavalia sp.	Pallar de los gentiles	Legume	31
Capsicum annuum	Pepper	C_3	11
Cucurbita maxima	Squash	C_3	41
Cucurbita sp.	Pumpkin	C_3	7
Cyperus sp.	Junco	C_3	17
Equisetum intectum	Horsetail	C_3	2
Erythroxylum coca	Coca	C_3	2
Furcraea andina	Cabuya	C_3	1
Gossypium barbadense	Cotton	C_3	30
Gynerium sagittatum	Caña brava	C_3	8
Inga feuilleei	Pacae	Legume	26
Ipomoea batatas	Sweet potato	C_3	2
Lagenaria siceraria	Mate	C_3	11
Manihot esculenta	Manihoc	C_3	3
Persea americana	Avocado	C_3	5
Phaseolus lunatus	Lima bean	Legume	40
Phaseolus sp.	Bean	Legume	52
Phaseolus sp. *Sub. nunas*	Nuña	Legume	18
Pouteria lucuma	Lucuma	C_3	48
Prosopis pallida	Huarango	Legume	2
Psidium guajava	Guava	C_3	25
Salix humboldtiana	Aliso	C_3	5
Sapindus saponaria	Boliche	C_3	3
Schinus molle	Molle	C_3	10
Typha angustifolia	Totora	C_3	12
Zea mays	Maize	C_4	122
			571

4.2. Methods

4.2.1. Cleaning the Samples

To prepare the samples for stable isotope analysis (SIA), the samples were first cleaned to remove all exogenous material (i.e., sediment). This was completed by cleaning the samples with a toothbrush, then placing them in a 50 mL beaker filled with Type I water (resistivity = 18.2 MΩ cm) in a sonicator for 10 minutes to remove sediment.

a) Only samples with a clearly visible superficial layer of dirt were first cleaned mechanically with a toothbrush.

b) All the samples were subjected to an ultrasonic bath using a VWR Symphony 97043-956 ultrasonic cleaner. Samples were place into 50 ml Pyrex beakers, with Type I water, covering the whole sample.

c) After 10 minutes of sonication with a temperature no higher than 30ºC the samples were decanted. It was important to keep the temperature relatively low (by adding ice to the ultrasonic bath) to avoid sample disintegration.

d) The water in the beakers was removed using a Pasteur Pipette attached to a vacuum flask.

e) Once the first round of sonication occurred, the procedure was repeated as many times as necessary until the water had no visible particulate matter. Discoloration of the water can be caused by the humics within the plant (Vaiglova et al. 2014) and a perfectly clear solution could not be achieved for some samples using the ultrasonic bath.

f) After all visible dirt particles were removed, the samples were dried using an oven at 55 ºC ≈ for 24-48 h, depending on the apparent dryness of the sample.

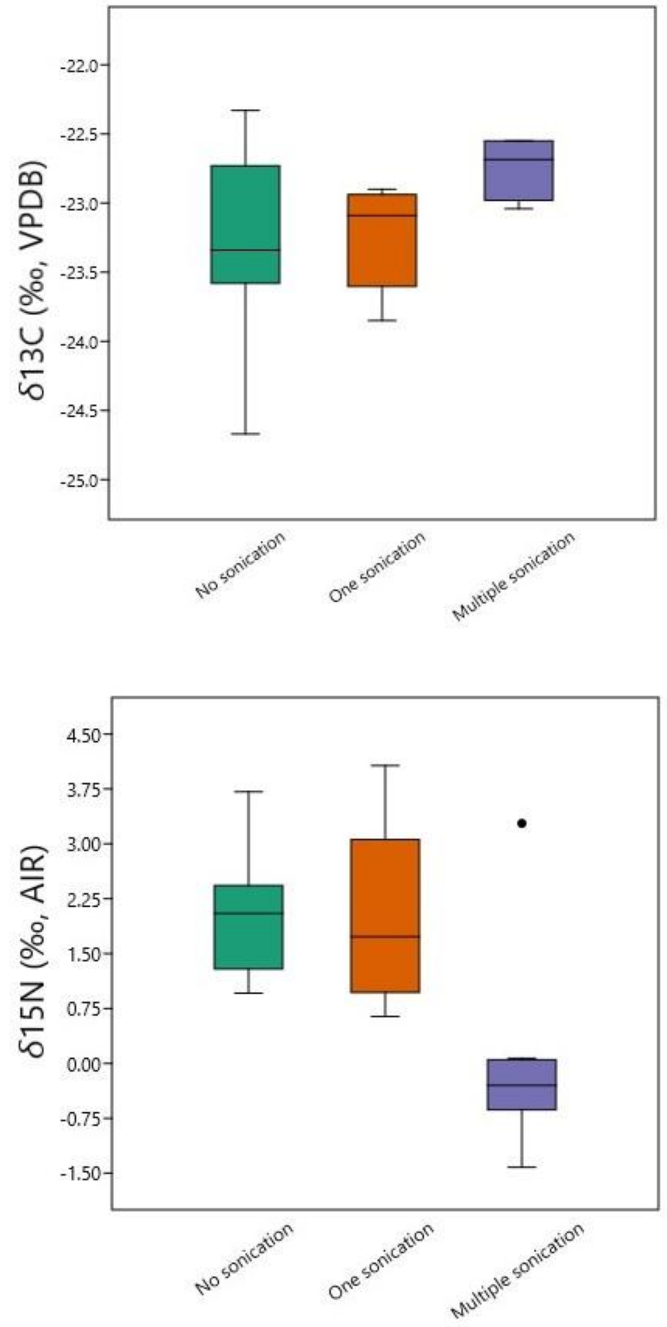

Figure 4.8. Comparison among sonication treatments for δ^{13}C and δ^{15}N of *Phaseolus lunatus* seeds.

To examine if sonication affected the isotopic values of the plants, the δ^{13}C and δ^{15}N values for *Phaseolus lunatus* seeds, with different numbers of sonication treatments, were compared (Figure 4.7). There was relatively little variation in the isotopic values between the different treatments, particularly for δ^{13}C, where the means differed by at most 0.28 ‰; there were no significant differences in δ^{13}C values among treatments (ANOVA; $F = 1.79$, $P = 0.18$). For δ^{15}N values, there were significant differences among treatments (ANOVA; $F = 8.55$, $P = 0.001$). Differences were found between no sonication and multiple sonications (Mann Whitney U test; $p = 0.005$) and one sonication and multiple sonications (Mann Whitney U test; $p = 0.005$). The samples with multiple sonication rinses had δ^{15}N values closest to what is considered ‘normal’ for legumes (−1 to +1 ‰) (Szpak et al. 2014), which suggests that multiple sonications did not degrade the plant material in such a way that the δ^{15}N values of the plants were altered. Moreover, these findings suggest that sonication did remove contaminating organic matter and that multiple sonications are superior to a single sonication treatment or no sonication since we would expect contaminating organic matter from the soil to have a higher δ^{15}N value than 0 ‰ and legumes to have δ^{15}N values that are very close to 0 ‰. The δ^{13}C values were also consistent with those expected for legumes. While multiple sonications creates some sample loss, this step does appear to reduce contamination, at least in beans in this environment.

4.2.2. Sample Grinding and Homogenization

Samples were ground with a Crescent Wig-L-Bug Amalgamator Model 3110-B (Industrial) to homogenize them prior to analysis. After grinding, around 1 g of each sample was place into a 15 ml polypropylene tube for storage.

4.2.3. Sample Chemical Pretreatment

Samples were treated with 10 ml of 0.5 M HCl at 80°C for 30 min and were then rinsed three times with Type I water (Vaiglova et al. 2014). Samples were then air dried at 55°C under normal atmosphere.

4.2.4. Sample weighing

Initially, 1000 ± 400 mg of sample was placed into 4.25 × 5 mm tin capsules. This initial analysis produced both δ^{13}C and δ^{15}N values. On the basis of replicate samples, the δ^{13}C values from this initial analysis were reliable but the δ^{15}N values were not, specifically for those samples with less than 4% N. Samples with <4 % N were reanalysed in N-only mode (wherein the CO_2 is removed from the sample after combustion) with the sample mass being optimized relative to the amount of N in the sample as determined in the initial analysis for δ^{13}C and δ^{15}N. To calculate the sample mass for the N-only analysis, we used the following formula, where the %N is the one obtained for a given plant sample in the initial δ^{13}C and δ^{15}N analysis (the samples mass is calculated to optimize the N_2 peak size using USGS40/glutamic acid as an exemplar with 9.5%N and a mass of 0.75 mg):

- Minimum sample mass = (9.5/%N)*(0.75)*(0.9)
- Maximum sample mass = (9.5/%N)*(0.75)*(1.04)

When applying this formula, some samples were too large to be properly combusted in the elemental analyser. For these samples, we used a sample mass of 3000 ± 500 mg and analysed most of these in triplicate or quadruplicate to ensure that the results were reproducible

4.2.5. Stable isotopes analyses

4.2.5.1. EA-IRMS

Analyses were conducted with a EuroEA 3000 Elemental Analyzer (EuroVector SpA) coupled to a Nu Horizon (Nu Instruments) continuous flow isotope ratio mass spectrometer (CF-IRMS) at the Trent University Water Quality Center. All samples were analysed for δ^{13}C and δ^{15}N as described above. For the N-only analysis, CO2 was removed from the system using EMASorb, a hygroscopic granular sodium hydroxide product.

4.2.5.2. Calibration, Accuracy, and Precision

4.2.5.2.1. Calibration

To assess analytical precision, we used a 22% sample duplication rate for δ^{13}C and 58% duplication, 13% triplication and 1% quadruplication rates for δ^{15}N. Sample measurements were calibrated relative to VPDB (δ^{13}C) and AIR (δ^{15}N) using USGS40, USGS63, and USGS66[1] (Table 4.2) (Qi et al. 2003; Qi et al. 2016).

Table 4.2. Standard reference materials used for calibration of δ^{13}C relative to VPDB and δ^{15}N relative to AIR.

Standard	Material	Accepted δ^{13}C (‰, VPDB)	Accepted δ^{15}N (‰, AIR)
USGS40	Glutamic Acid	−26.39±0.04	−4.52±0.06
USGS63	Caffeine	−1.17±0.04	+37.83±0.06
USGS66	Glycine	−0.67±0.04	+40.83±0.20

4.2.5.2.2. Accuracy and Precision

The following standards were used to monitor accuracy and precision (Table 4.3). Standards with relatively high C:N ratios, approximating those found in plants, were

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[1] In one case, our internal standard (SRM-17) was used in the calibration because there was an instrument failure and an insufficient number of the other calibration standards were analyzed that day.

predominantly used as check standards, especially: phenylaline (C:N=9.0), chitin powder (C:N=7.9), and amygdalin (C:N=21.1).

Table 4.3. Standard reference materials used to monitor internal accuracy and precision.

Standard	Material	Mean δ^{13}C (‰, VPDB)	Mean δ^{15}N (‰, AIR)
SRM-17	Phenylalanine	−12.40±0.09	−0.25±0.27
SRM-18	Amygdalin	−24.41±0.07	+3.18±0.22
SRM−21	Histidine	−9.77±0.08	−7.30±0.24
SRM−23	Glycine	−41.47±0.06	+2.58±0.18
SRM-24	Chitin Powder	−21.31±0.04	+0.19±0.52
SRM−25	Caffeine	−33.24±0.08	−12.87±0.29

Table 4.4 summarizes the mean and standard deviations of carbon and nitrogen isotopic compositions for all check (quality assurance) standards, as well as the standard deviation for all calibration (quality control) standards – the mean of the calibration standard for an individual run is predetermined to calibrate the data.

Table 4.4. Mean and standard deviation of all check (QA) and calibration standards for all analytical sessions containing data presented in this paper. Note that means for calibration standards are not presented as they are pre-determined to be equal to the known value.

Standard	**n**	**δ^{13}C (‰, VPDB)**			**δ^{15}N (‰, AIR)**		
USGS40	115		±	0.03		±	0.24
USGS63	114		±	0.28		±	0.35
USGS66	114		±	0.14		±	0.40
SRM-17	118	−12.40	±	0.09	−0.25	±	0.35
SRM-18	108	−24.41	±	0.05	+3.18	±	0.56
SRM-21	1				−7.30		
SRM-23	1				+2.58		
SRM-24	247	−21.31	±	0.03	−0.36	±	0.41

SRM-25	20	−33.24	±	0.06	−12.87	± 0.20

4.2.5.2.3. Analytical Uncertainty

Standard uncertainty was calculated using the method present by Szpak et al. (2017). Standard uncertainty was determined to be ±0.20 ‰ for δ^{13}C and ±0.70 ‰ for δ^{15}N. The precision of the isotope values (*u(Rw)*) was determined to be ±0.17 ‰ for δ^{13}C and ±0.53 ‰ for δ^{15}N based on repeated measurements of calibration standards, check standards, and sample replicates. The accuracy or systematic error (*u(bias)*) was determined to be ±0.06 ‰ for δ^{13}C and ±0.31 ‰ for δ^{15}N based on the difference between the observed and known δ values of the check standards and the long-term standard deviations of these check standards. The pooled standard deviation for the duplicate pairs was ±0.22 ‰ for δ^{13}C and ±0.62 ‰ for δ^{15}N. The higher uncertainty for δ^{15}N is the product of both the heterogeneity of the plant tissues as well as the lower precision on isotopic measurements of samples with low N contents on the EA-IRMS system that was used.

4.2.6. Statistical analyses

To assess differences in the isotopic compositions of the different plant samples a Shapiro–Wilk test (Shapiro and Wilk 1965) was first used to asses the normality of each distribution. For those comparisons involving non-normal distributions Mann–Whitney U test (Mann and Whitney 1947) were used. For those with normal distributions comparisons were made by using unpaired t-tests (Student 1908; Welch 1947). For comparisons among three or more groups, normality was also assessed with a Shapiro–Wilk test (Shapiro and Wilk 1965). For those comparisons involving non-normal distributions Pairwise Whitney U tests were used (Mann and Whitney 1947). For those with normal distributions a one-way analysis of variance (ANOVA) (Girden 1992) was performed. Homogeneity of variance was then assessed using an F test and if the variances were equal, a post hoc Tukey's HSD was used for pairwise comparisons. If the variances were unequal, a Dunn's test was used. The correlation between the $\delta^{13}C$ and $\delta^{15}N$ values of C_3 plant taxa with >10 samples was assessed using Spearman's ρ.

5. Results and Discussion

5.1. Reliability of the Isotopic Measurements of Desiccated Remains

As discussed in Chapter 3, it was long assumed that naturally desiccated botanical remains were unsuitable for stable isotope analysis (DeNiro and Hastorf 1985). There was a suspicion that the natural desiccation of plants in post-depositional processes might be causing fractionation and therefore producing much higher-than-normal δ^{15}N values that would not accurately reflect the values when the plants were growing. This is a debate that is most relevant to areas with excellent organic preservation, such as the Peruvian desertic coast, but has not been explored in other areas, such as Europe, where most isotopic analyses of ancient plant remains have been carried out (Fiorentino et al. 2015). More recent studies have demonstrated the viability of desiccated plant samples for stable isotope analysis (Metcalfe and Mead 2019; Szpak and Chiou 2020). More than 95% of the botanical remains found at Cerro de Oro, and analysed in this research, were desiccated rather than charred. Therefore, testing the reliability of the isotopic measurements of charred botanical remains was important. Maize cobs were the only sample material that produced enough charred and desiccated material to make a meaningful comparison between the two sample types. There was little to no difference between the desiccated (mean = +13.9 ± 2.8 ‰ and charred (mean = +13.7 ± 5.2 ‰) maize cobs (Mann Whitney U test; $p = 0.53$) (Figure 5.1). This observation is consistent with the idea that desiccated remains can produce reliable carbon and nitrogen isotopic measurements as suggested by Szpak and Chiou (2020) and Metcalfe and Mead (2019). Following the logic of Szpak and Chiou (2020), if stable carbon and nitrogen isotopic measurements of charred plant remains are reliable, the evidence from Cerro de Oro suggests that there is no reason to think that this is not the case for desiccated remains.

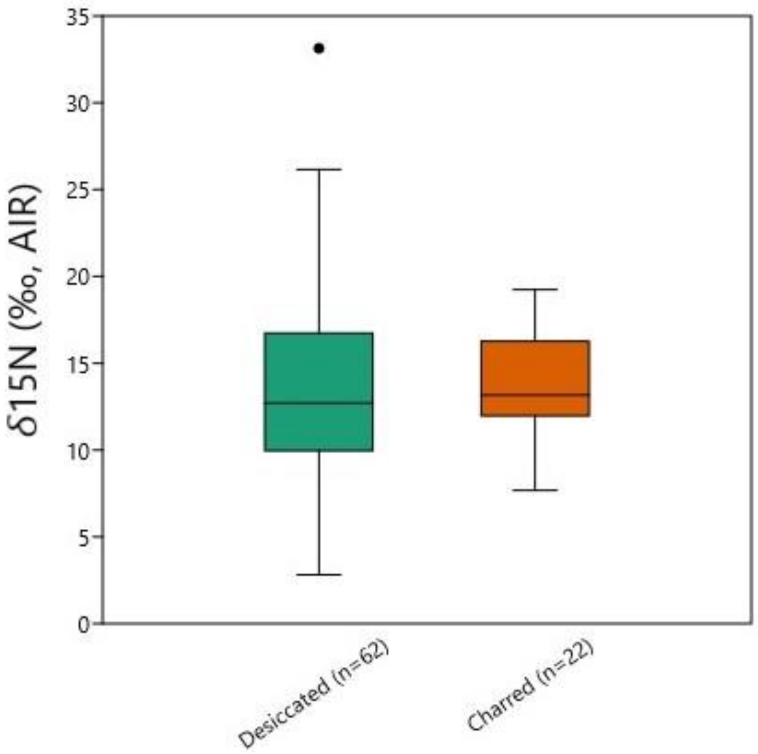

Figure 5.1. Box plot of δ^{15}N for desiccated and charred maize cobs from Cerro de Oro.

Another analytical concern with botanical samples is their low nitrogen content. If plant δ^{15}N values have been altered in the burial environment, it is possible that δ^{15}N values increase as the %N in the remaining material decreases (Szpak and Chiou 2020). A comparison of the δ^{15}N and %N values of different tissues from the same plants from Cerro de Oro suggests that δ^{15}N is not increasing as %N decreases (Figure 5.2). For example, cucurbits had an average %N of 1.7 ± 1.8‰ for the peduncles and 4.1 ± 1.2‰ for the seeds, but very similar δ^{15}N values for both tissues, +12.4 ± 2.3 ‰ and +11.6 ± 2.8 ‰, respectively. This is also the case for *Inga feuillei*;

pods had %N values of 1.4 ± 0.5 ‰ and seeds had %N values of 3.3 ± 0.6 ‰, while δ^{15}N values were +5.6 ± 4.2 ‰ and +3.7 ± 1.8 ‰, respectively.

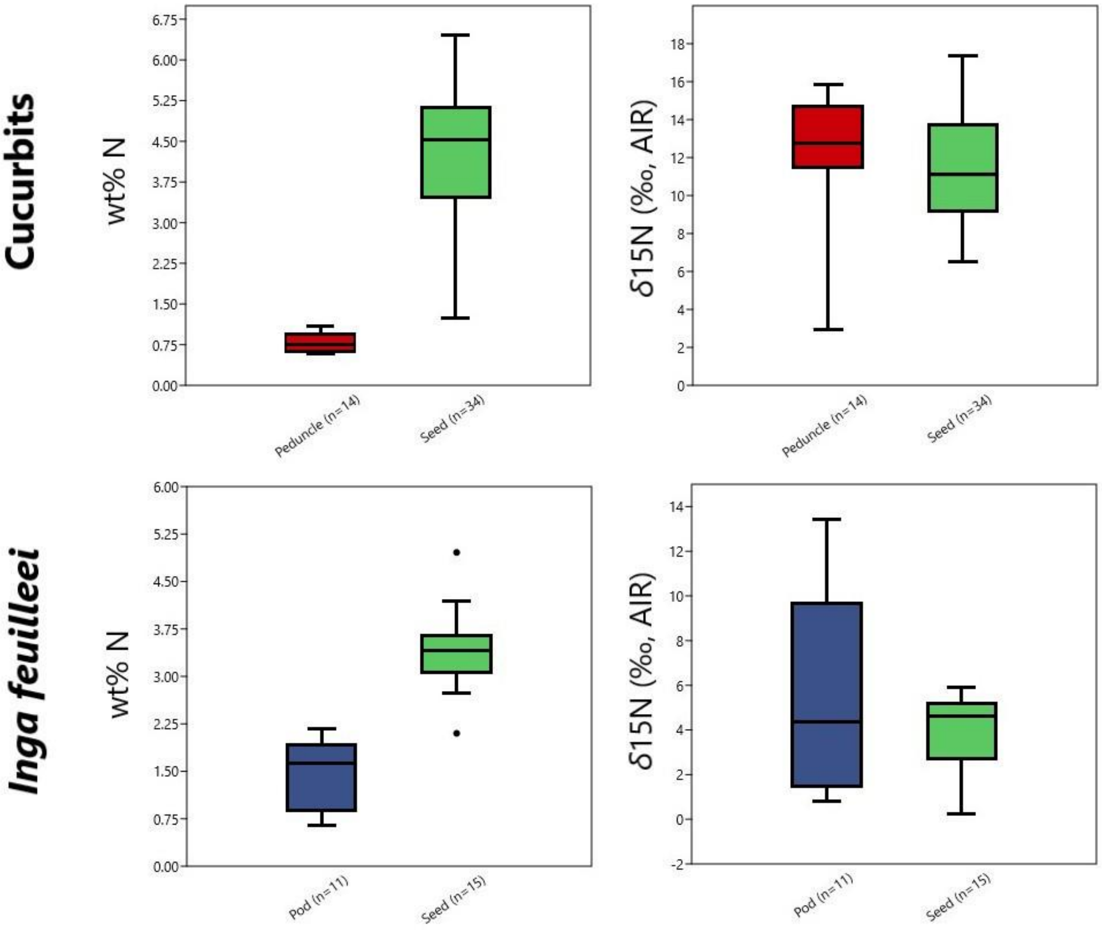

Figure 5.2. Comparison of different tissue %N and δ^{15}N for cucurbits and *Inga feuilleei*.

Finally, the quantity and preservation of the samples found at Cerro de Oro has allowed for the comparison of different tissues that belong to the same individual plant. For example, cotton (*Gossypium barbadense*) bolls contain seeds, fibres, and the boll cortex. Even though these tissues have very different %N contents, they had very similar δ^{15}N values (Table 5.1). This is further evidence of the reliability of the samples as different parts of the plant, with different %N produced similar δ^{15}N values.

Table 5.1. Comparison of *Gossypium barbadense* subsamples δ^{13}C, δ^{15}N, % C and % N. Sample 15248.x and 15429.x each represent different parts of distinct individuals.

Sample Number	**Part**	**$\delta^{13}C_{VPDB}$/‰**	**$\delta^{15}N_{AIR}$/‰**	**wt% C**	**wt% N**
15248.1	Boll cortex	−21.51	+14.6	43.9	1.0
15248.2	Fiber	−20.28	+15.7	42.6	0.5
15248.3	Seed	−20.21	+15.6	45.3	1.6
15249.1	Boll cortex	−21.96	+15.5	44.0	0.8
15249.2	Fiber	−21.49	+16.2	44.3	0.5
15249.3	Seed	−21.74	+15.1	47.1	4.5

Therefore, with this analysis, we have found additional evidence that supports the reliability of naturally desiccated archaeological botanical samples for stable carbon and nitrogen isotope analysis, in contradiction to DeNiro and Hastorf (1985). This is important because the analysis of desiccated plant remains creates more opportunities with respect to plant taxa and tissues types than could be analysed by relying on charred samples alone.

5.2. Cerro de Oro Plant Isotopic Compositions

Table 5.2 includes the resulting average and standard deviation for δ^{13}C and δ^{15}N values and %C and %N for all the 31 analysed taxa. All of the data for each specimen are presented in their entirety in Appendix 2.

Table 5.2. δ^{13}C, δ^{15}N, %C and %N average and standard deviation results for all the taxa analysed from Cerro de Oro.

Taxonomic name	Common name	Type of plant	n	δ^{13}C$_{\mathrm{VPDB}}$/‰	δ^{15}N$_{\mathrm{AIR}}$/‰	wt% C	wt% N
Arachis hypogaea	Peanut	Legume	25	−24.73 ± 1.20	+7.5 ± 3.0	43.4 ± 2.7	1.1 ± 1.0
Baccharis sp.	Chilco	C_3	1	−22.95	+25.2	48.0	0.4
Bunchosia armeniaca	Ciruela del fraile or cansaboca	C_3	1	−25.52	+12.0	44.3	0.9
Caesalpinia spinosa	Tara	Legume	1	−24.32	+16.2	45.4	1.5
Canna indica	Achira	C_3	13	−24.63 ± 1.34	+14.3 ± 6.4	40.9 ± 3.8	1.7 ± 0.8
Cannavalia sp.	Pallar de los gentiles	Legume	31	−24.08 ± 1.23	+3.4 ± 1.5	41.7 ± 1.8	2.6 ± 1.1
Capsicum sp.	Pepper	C_3	11	−26.26 ± 1.62	+11.5 ± 2.8	45.1 ± 2.1	1.5 ± 0.6
Cucurbita maxima	Squash	C_3	41	−25.36 ± 1.55	+11.6 ± 3.1	49.0 ± 5.2	3.4 ± 1.8
Cucurbita sp.	Pumpkin	C_3	7	−24.54 ± 1.15	+12.7 ± 1.2	47.2 ± 1.5	2.4 ± 1.5
Cyperus sp.	Junco	C_3	17	−26.05 ± 0.57	+8.9 ± 2.4	40.4 ± 3.4	1.6 ± 0.3
Equisetum intectum	Horsetail	C_3	2	−22.73 ± 1.20	+11.1 ± 2.1	37.8 ± 3.1	0.6 ± 0.2
Erythroxylum coca	Coca	C_3	2	−23.99 ± 1.12	+15.5 ± 2.1	47.7 ± 1.0	2.3 ± 0.3
Furcraea andina	Cabuya	C_3	1	−26.32	+11.4	45.3	1.5
Gossypium barbadense	Cotton	C_3	30	−22.40 ± 1.38	+13.7 ± 2.9	45.0 ± 5.6	2.1 ± 1.6
Gynerium sagittatum	Caña brava	C_3	8	−25.65 ± 0.56	+12.3 ± 7.1	43.8 ± 8.7	0.3 ± 0.1
Inga feuilleei	Pacae	Legume	26	−24.62 ± 1.24	+4.5 ± 3.1	44.5 ± 1.3	2.6 ± 1.1
Ipomoea batatas	Sweet potato	C_3	2	−25.12 ± 0.30	+15.4 ± 0.4	40.3 ± 2.1	0.7 ± 0.0
Lagenaria siceraria	Mate	C_3	11	−24.36 ± 1.23	+14.5 ± 1.9	47.4 ± 2.1	1.8 ± 1.5
Manihot esculenta	Manihoc	C_3	3	−25.02 ± 2.30	+6.7 ± 3.9	38.7 ± 2.1	0.9 ± 0.4
Persea americana	Avocado	C_3	5	−24.92 ± 0.96	+12.2 ± 2.4	39.3 ± 4.4	2.4 ± 0.8
Phaseolus lunatus	Lima bean	Legume	40	−25.27 ± 1.61	+2.2 ± 1.1	38.7 ± 6.3	3.8 ± 1.4
Phaseolus sp.	Bean	Legume	52	−24.40 ± 1.42	+3.4 ± 2.4	44.7 ± 3.6	3.2 ± 1.7
Phaseolus sp. *Sub. nunas*	Nuña	Legume	18	−25.50 ± 1.53	+3.0 ± 0.9	54.3 ± 5.0	5.9 ± 1.0

Taxonomic name	**Common name**	**Type of plant**	**n**	$\delta^{13}C_{VPDB}$/‰	$\delta^{15}N_{AIR}$/‰	**wt% C**	**wt% N**
Pouteria lucuma	Lucuma	C_3	48	−26.01 ± 1.56	+12.8 ± 6.0	46.5 ± 3.8	1.8 ± 1.5
Prosopis pallida	Huarango	Legume	2	−25.02 ± 1.52	+6.9 ± 2.5	45.6 ± 1.4	2.1 ± 1.1
Psidium guajava	Guava	C_3	25	−24.61 ± 1.67	+14.0 ± 3.1	46.0 ± 3.6	1.4 ± 0.5
Salix humboldtiana	Aliso	C_3	5	−25.86 ± 1.36	+12.6 ± 3.6	43.1 ± 3.6	0.9 ± 0.5
Sapindus saponaria	Boliche	C_3	3	−24.84 ± 1.10	+16.6 ± 5.3	46.7 ± 1.2	1.9 ± 1.6
Schinus molle	Molle	C_3	10	−25.01 ± 1.15	+8.2 ± 7.2	46.7 ± 1.6	0.7 ± 0.4
Typha angustifolia	Totora	C_3	12	−26.42 ± 1.13	+15.4 ± 3.0	44.1 ± 2.5	1.0 ± 0.9
Zea mays	Maize	C_4	122	−9.67 ± 0.61	+13.1 ± 5.1	47.7 ± 14.0	1.1 ± 0.9
		Total	**575**				

Stable carbon and nitrogen isotope data in archaeological studies are often presented in bivariate scatterplots in a form of ‘isotopic foodwebs’. This is usually the case when consumer (e.g., human) isotopic data are compared to possible food sources. Figure 5.3 shows the isotopic foodweb for the most abundant plant taxa from Cerro de Oro.

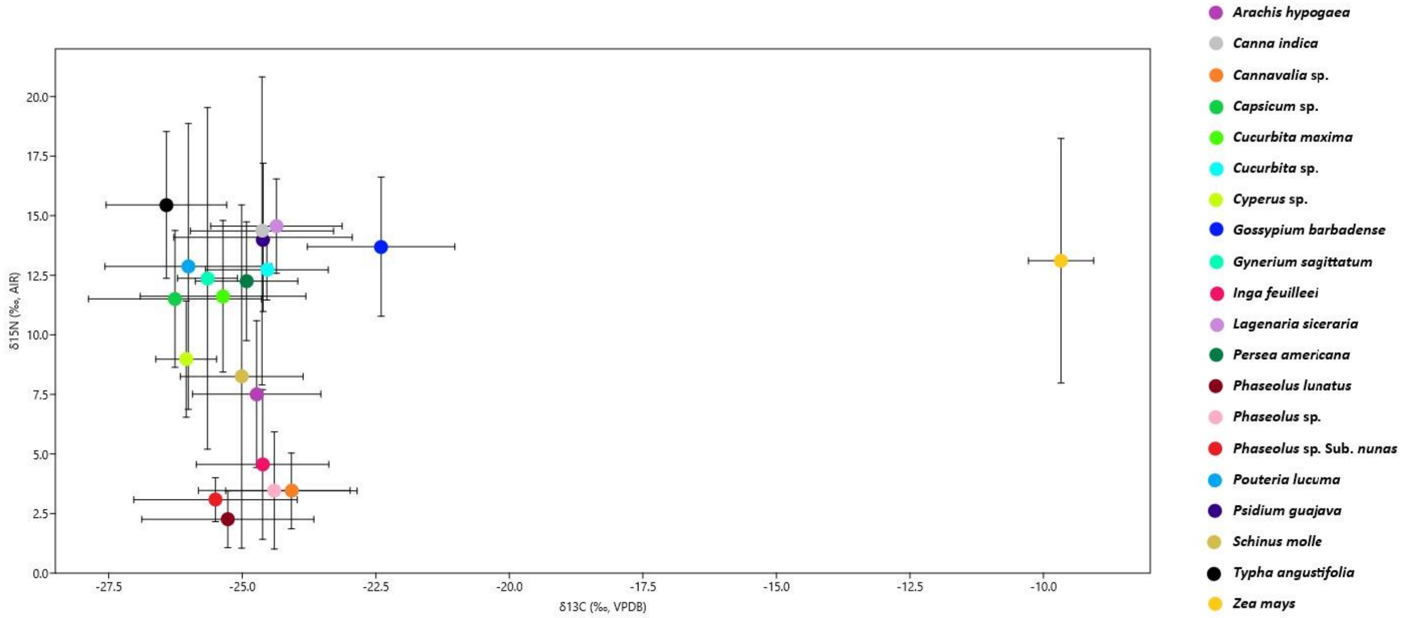

Figure 5.3. δ^{13}C and δ^{15}N (means ± 1 standard deviation) for the most abundant taxa at Cerro de Oro.

Three separate groups or clusters can be seen in Figure 5.3: leguminous plants, C_3 non-legumes, and C_4 plants. Because it is not possible to quantitatively interpret human diet composition using stable isotope data with many food sources, it is necessary to combine isotopically similar food sources (Cheung and Szpak 2021). These three isotopically distinct groups of plants are presented in Figure 5.4 and summarized in Table 5.3.

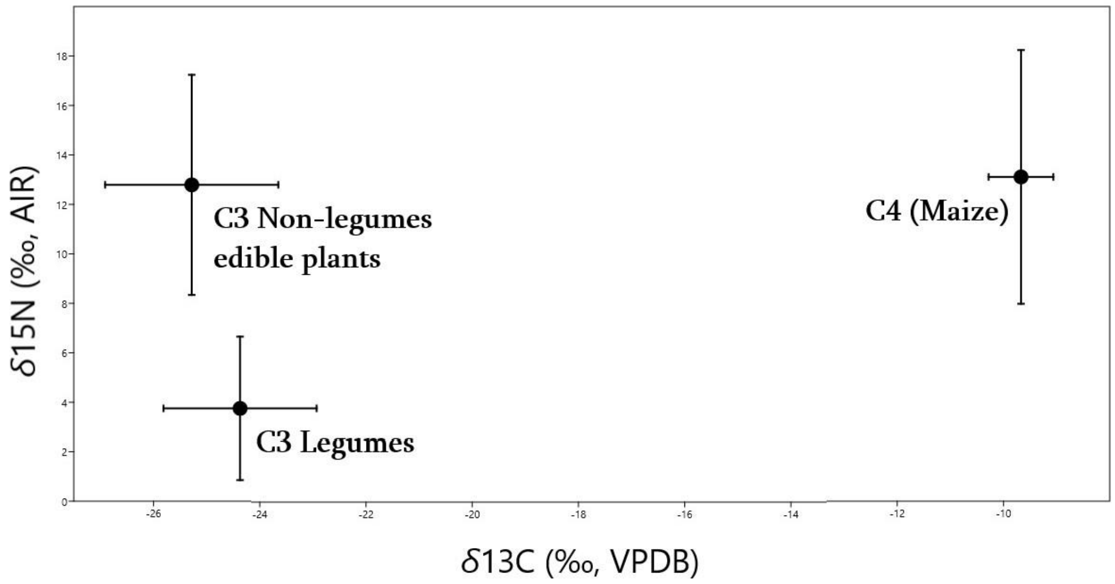

Figure 5.4. δ^{13}C and δ^{15}N (means ± 1 standard deviation) for the three different types of plants at Cerro de Oro.

The isotopic compositions for these plants represent the botanical isotopic baseline of the inhabitants of Cerro de Oro. This is the most extensive regionally and temporally-specific baseline of its kind for the central Andes and the Americas more generally. While creating unique baselines for specific sites is ideal (Casey and Post 2011), this baseline will be of tremendous help to other researchers working in this region since paleodietary studies have traditionally utilized isotopic data from modern plant taxa, which are unlikely to represent the variation observed in ancient plants as discussed below. These data will also be useful for studies examining animal husbandry practices at the site via isotopic analysis. Although the isotopic compositions of marine fauna from this region and time period are currently unknown, the relatively high δ^{15}N values observed for the maize and C_3 non-legumes (discussed in more detail below in Section 5.4.1) suggest that distinguishing between the consumption of plants and marine resources may be less straightforward than might be assumed.

Table 5.3. δ^{13}C and δ^{15}N (means ± 1 standard deviation) values for the three different types of plants at Cerro de Oro.

Type of plant	**$\delta^{13}C_{VPDB}$/‰**	**$\delta^{15}N_{AIR}$/‰**
C_3 legumes	−24.37±1.44	+3.7±2.9
C_3 Non-legume	−25.05±1.79	+12.6±4.6
C_3 Non-legume edible	−25.27±1.63	+12.7±4.4
C_4	−9.67 ± 0.61	+13.1 ± 5.1

5.3. Comparisons with Other Baselines and Modern samples

Studies of human diet using stable isotopes often make use of modern plant isotopic compositions for their baselines. In this context, ‘baselines’ are analogous to ‘sources’ in quantitative mixing models and represent the isotopic compositions of foods that may have been consumed. The vast majority of research on stable carbon and nitrogen isotope analysis in Andean archaeology has relied upon two types of comparative baselines: published isotopic data from other regions and modern floral and faunal data.

The most commonly used baseline has been previously published data, some of which are decades old, that have been used to create isotopic baselines for various environments using animals and plants (Cadwallader 2012; DeNiro and Hastorf 1985; Marsteller 2015; Szpak and Chiou 2020; Tieszen and Chapman 1992). This type of comparison is often problematic, as samples collected in places with very different ecological conditions or cultural practices (e.g., modern agricultural practices) are often not broadly applicable across time and space. As explained in chapter 3, there are a large number of factors that can alter the isotopic values of plants, and therefore, comparisons between consumers (e.g., humans) and potential foods drawn across wide spans of time and space are often unreliable. For example, one of the most widely used studies, which pioneered this type of analysis, is that of Tieszen and Chapman (1992). This study relied on modern plant samples from the Atacama Desert, one of the most extreme and arid ecosystems on earth and modern marine and terrestrial fauna from the Arica coast and highland regions. Both the age and geographical origin of these samples can make comparisons with isotopic data from ancient human populations problematic. If we had used these baseline data to interpret human subsistence at Cerro de Oro using the stable isotope compositions of human remains, the interpretations would be inaccurate. For example, the *Zea mays* δ^{13}C values presented by Tiesezen and Chapman were −12.8 ± 0.4 ‰, while maize at Cerro de Oro had an average δ^{13}C value of −9.67 ± 0.6 ‰. The lack of δ^{15}N values for plants in the Tieszen and Chapman study might also suggest that relatively high δ^{15}N values in human remains had to be explained by the consumption of marine resources. In other isotopic foodwebs used in the Andes, plants have often been assumed to have low δ^{15}N values (e.g., Carmichael et al. 2014; Gerdau-Radonić et al. 2015). Relying on the Tieszen and Chapman data would therefore cause the importance of agricultural plants in the diet to be underestimated. Aside from the issues of using modern isotopic data to interpret results from archaeological contexts, isotopic variability can be also significant when comparing data from archaeological sites from the same period with similar environmental conditions because of variable cultural practices.

Figure 5.5 compares δ^{15}N data from some of the most common plant taxa from Cerro de Oro with those presented by Szpak and Chiou (2020) from the Moche sites of Cerro Chepen and San Jose de Moro. These samples are from coastal sites in the north coast of the Central Andes, also dating from the transition between Early Intermediate Period to Middle Horizon.

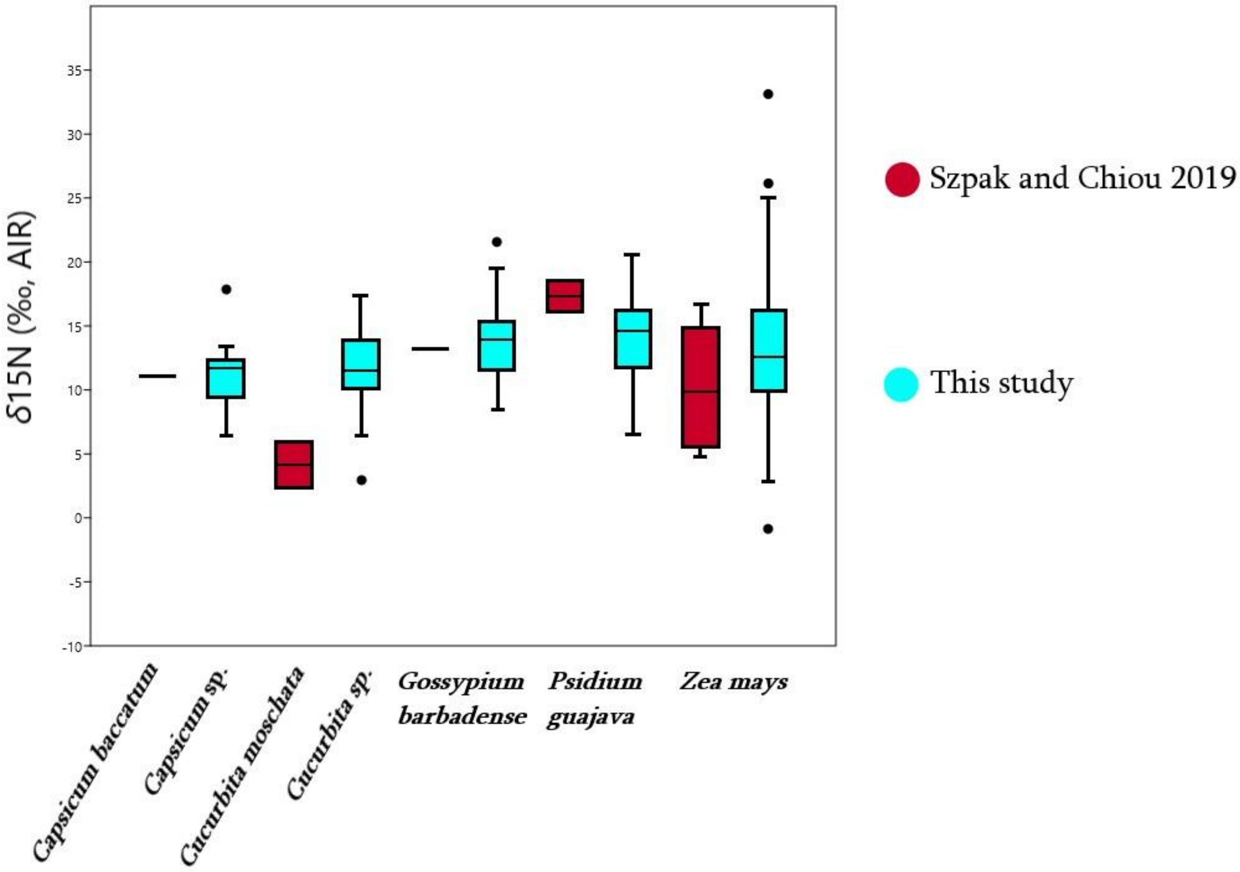

Figure 5.5. Comparison of δ^{15}N between Cerro de Oro samples and archaeological samples from the Moche sites of San Jose de Moro and Cerro Chepén on the north coast of Peru.

The δ^{15}N values of the plant remains from Cerro Chepen and San Jose de Moro were relatively high (+11.2 ± 4.4 ‰ for charred remains and +10.1 ± 5.1 ‰ for desiccated remains), suggesting that the inhabitants were making use of animal manure to improve soil fertility (Szpak and Chiou 2020). The values that were found for the plants at the Moche sites are similar to, but generally slightly lower than, the plants from Cerro de Oro (Figure 5.5). It is important to point out that the sample size for the Moche sites was extremely small, and that study may not have adequately captured the amount of isotopic variation present at the site. This small sample size also means that statistical comparisons between the two studies are not possible.

The use of modern samples as a comparative isotopic baseline is another approach to dietary reconstruction (Gerdau-Radonić et al. 2015). Figures 5.6 and 5.7 compare the isotopic compositions of modern samples collected from northern Peru with archaeological samples from Cerro de Oro. The modern samples have a much smaller range of variability than the archaeological samples and there are differences in the mean isotopic compositions for some key taxa.

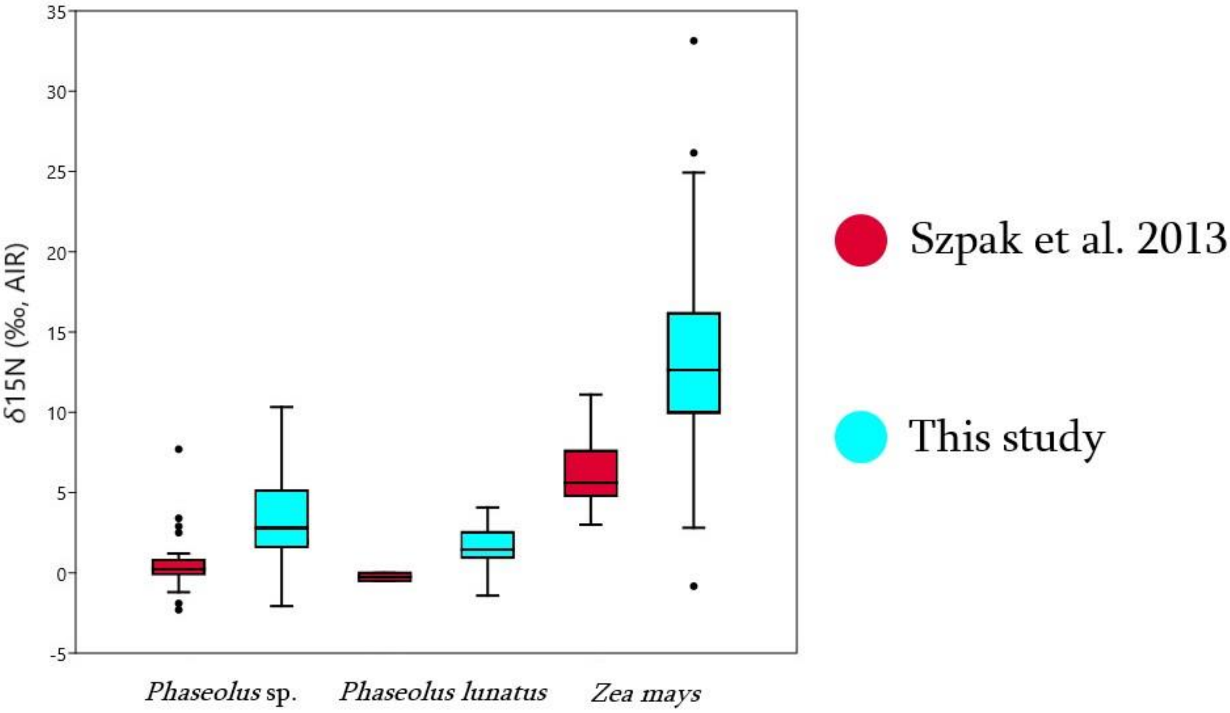

Figure 5.6. Comparison of δ^{15}N for modern plants collected in the Moche Valley (Szpak et al. 2013) and archaeological plant samples from Cerro de Oro.

For the data from northern Peru presented by (Szpak et al. 2013) *Phaseolus* δ^{15}N values were around 0 ‰, which is what is expected for legumes (Figure 5.7). There was, however, much more isotopic variation and higher overall δ^{15}N values for the archaeological samples from Cerro de Oro (Figure 5.7) A significant difference was found for *Phaseolus* sp. δ^{15}N values (Mann Whitney U test; p < 0.001). More variation was found for Cerro de Oro *Phaseolus lunatus* (Figure 5.7), however the small sample size in Szpak et al. (2013) does not allow for a statistical comparison. *Zea mays* was also characterized by much more variation and higher overall δ^{15}N values at Cerro de Oro relative to the modern samples (Figure 5.7); this difference was statistically significant (t-Test; t =10.62, $p < 0.001$). These data demonstrate that if the modern plant δ^{15}N values presented by Szpak et al. (2013) were used in an isotopic paleodiet study at Cerro de Oro, they would result in very inaccurate interpretations of the human diet composition, specifically, the amount of protein derived from crops would likely be underestimated for individuals with relatively high δ^{13}C and δ^{15}N values.

An overly simple example using a two source linear mixing model (Equations 1 and 2) can demonstrate the potential impact of these differences (Schwarcz 1991).

Equation 1 $$X_1 + X_2 = 1$$

Equation 2 $$(\delta^1 \times X_1) + (\delta^2 \times X_2) = \delta^C$$

Where X_1 and X_2 are the proportions of two sources with distinct isotopic compositions ($\delta^1$and δ^2) and δ^c represents the isotopic composition of the consumer (mixture) corrected for trophic discrimination.

Assume that a human has a bone collagen δ^{15}N value of +19 ‰ and marine foods at Cerro de Oro have an average δ^{15}N value of +20 ‰ (δ^1). We will assume a collagen-diet trophic discrimination factor of +4 ‰ (Bocherens and Drucker 2003), giving the consumer a trophic discrimination-corrected isotopic composition of +15 ‰ (δ^c). Using a δ^{15}N value of +5 ‰ for maize (δ^2, following the modern data in Szpak et al. 2013), this would suggest that maize contributed 33% of dietary protein and marine foods contributed 67% of dietary protein for our hypothetical consumer. If, however, we use the δ^{15}N value of +13 ‰ for maize determined in this study and keep everything else constant, this would change the relative contributions of maize and marine foods to 71% (for maize) and 29% (for marine foods). While it is certainly true that other foods would have contributed to the diet and this example is a gross oversimplification, the underlying math of this problem highlights how inaccurate quantitative dietary reconstructions can be with inappropriate baseline data. Qualitative interpretations of stable isotope scatterplots presenting foods and consumers work on a similar framework and the same danger exists. The strength of a dietary reconstruction is limited by the quality of the source (i.e., food) isotopic data (Cheung and Szpak 2021), which underscores the importance of these plant stable isotope data from Cerro de Oro.

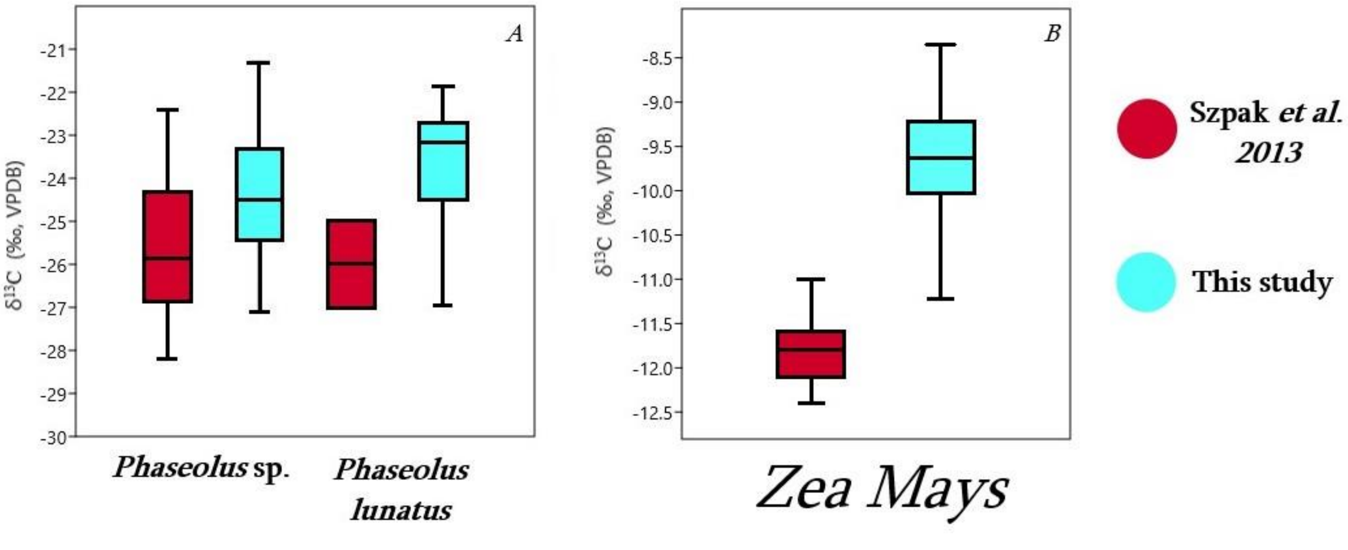

Figure 5.7. Comparison of between modern (Szpak et al. 2013) and Cerro de Oro beans (A) and maize (B).

Modern food δ^{13}C values also differed from the archaeological results from Cerro de Oro, but less dramatically than the δ^{15}N values (figure 5.7). Modern *Phaseolus* sp.

samples have δ^{13}C values of −25.7±1.6 ‰ (Szpak et al. 2013) while the plants at Cerro de Oro had δ^{13}C values of −24.40±1.42 ‰. This difference was not statistically significant (*t*-Test; t =1.22, p = 0.53) Similar results were found for *Phaseolus lunatus*; modern samples had a δ^{13}C= −26.0 ± 1.4 ‰ and archaeological samples had δ^{13}C values of −25.27 ± 1.61 ‰. Szpak et al. (2013) presented a sample size of n = 2 for this taxon, precluding statistical comparison. The difference in δ^{13}C was much more pronounced in *Zea mays* grains with δ^{13}C values of −11.8±0.4 ‰ for modern samples and −9.67 ± 0.61 ‰ for archaeological samples from Cerro de Oro – a difference of more than 2 ‰ that was statistically significant (Mann Whitney U test; $p < 0.001$). A similar, but more subtle, problem as the one highlighted above for δ^{15}N values would exist here as the δ^{13}C values of plants at Cerro de Oro are systematically higher than the modern plant data presented by Szpak et al. (2013), even though these modern data have been corrected to account for the Suess Effect. Collectively, these demonstrate that δ^{13}C values from modern plants and plants from other regions are more likely to be broadly applicable than δ^{15}N values for palaeodietary studies, at least for the central Andes.

5.4. Agricultural Intensification at Cerro de Oro

The generally high δ^{15}N values for plants at Cerro de Oro that we observed in this study are consistent with the application of organic fertilizer (i.e., manure of some type) (Figure 5.8). Generally, we can assume that most of the C_3 non-legume crops have higher δ^{15}N values than expected for unfertilized plants, most likely suggesting fertilization with camelid dung or fish carcasses. This interpretation is based on the faunal remains found at Cerro de Oro, as is difficult to directly a single fertilizer source from the isotopic results, as discussed previously. When examining the plant remains from Cerro de Oro, the following species had particularly high $\delta^{15}N$ values for at least some of the analyzed samples (i.e., over 20 ‰): *Canna indica*, *Gossypium barbadense*, *Pouteria lucuma*, *Psidium guajava*, and *Zea mays* (Figure 5.8). These unusually high $\delta^{15}N$ values are best explained by seabird guano fertilization. Plants with $\delta^{15}N$ values above 20 ‰ are relatively rare at Cerro de Oro (3.6% of all analyzed samples), suggesting that the most important source of fertilizer was camelid dung, fish carcasses, or some combination of these.

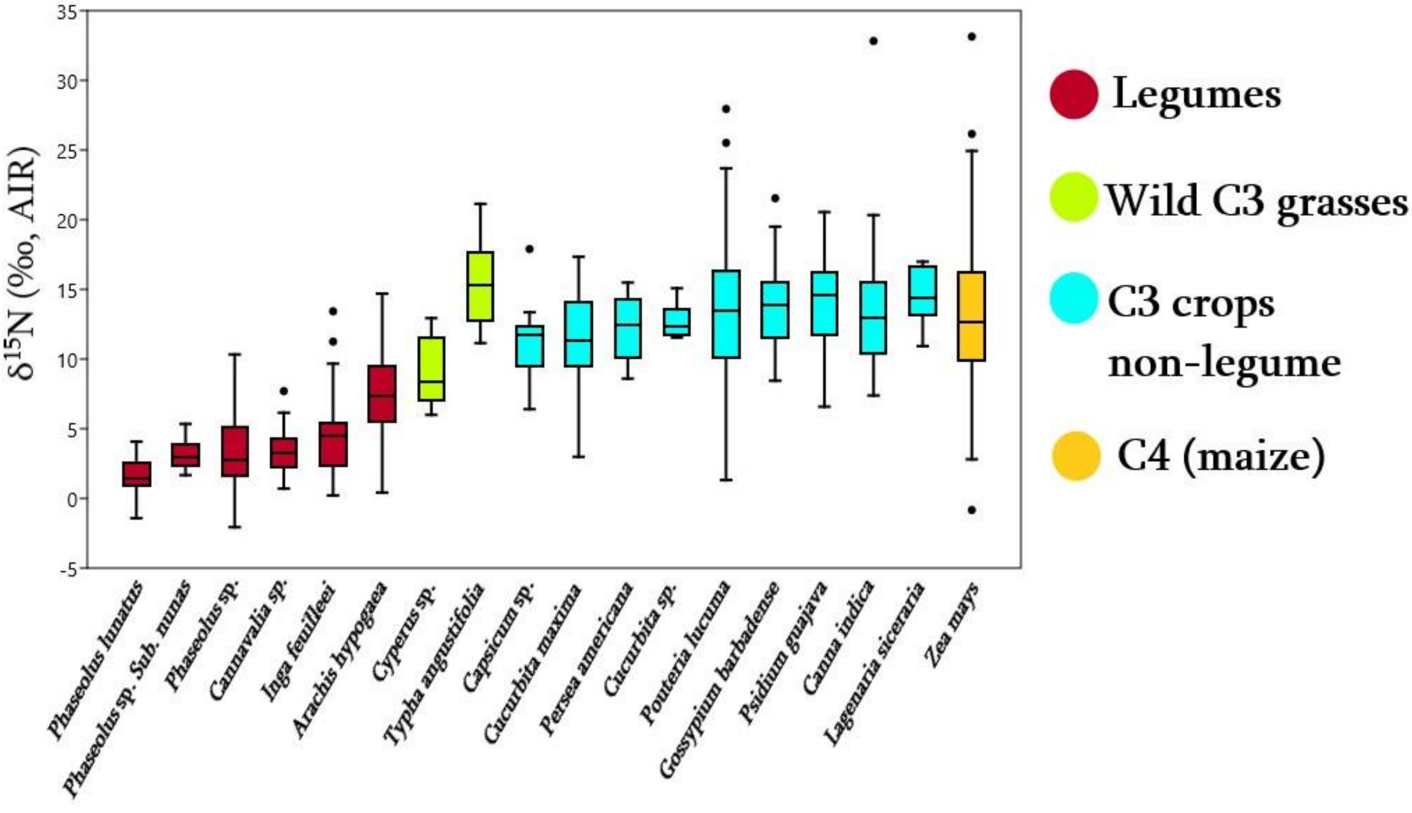

Figure 5.8. $\delta^{15}N$ comparison among the most represented taxa by types of plants

Maize was by far the most consumed plant at Cerro de Oro, totalling around the 30% of the botanical remains recovered at the site (Fernandini 2018, 2019; González Gomez de Agüero 2019). The role of maize during the different stages of Andean prehistory is one of the most addressed topics in archaeological studies in the region. Maize has also figured prominently in isotopic analyses in archaeology because it is a C_4 plant and its consumption is relatively easy to detect compared to other crops (Burger and van der Merwe 1990; Finucane et al. 2006; Finucane 2009; Goldstein 2003; Hastorf 1991; Kellner and Schoeninger 2008). It is been proposed that the emergence of sociopolitical forms such as states (e.g. Wari) (Finucane 2009) since the MH is related to the higher production and consumption of maize (Goldstein 2003; Hastorf and Johannessen 1993; Isbell 1988; Kellner and Schoeninger 2008), and therefore with the agriculture intensification and population growth. Maize played an important role in the emergence of Cerro de Oro as a monumental settlement and regional centre. Its $\delta^{15}N$ values are significantly more variable than the rest of the plants, except for *Pouteria lucuma* (Table 5.2, Figure 5.8). This variation in $\delta^{15}N$ reflects the use of different kinds of fertilizers. Camelid dung was probably the most important fertilizer use, not just for maize but for all crops at Cerro de Oro. Camelid husbandry was part of the domestic spaces, with corrals (Fernandini 2020) and a lot of camelid dung found within habitational spaces in different part of the site.

Fernandini (2020) and González Gómez de Agüero (2019) proposed the presence of up to four different groups in the Cerro de Oro based on the diet and cooking structures styles. Access to marine resources may have varied among groups or neighbourhoods within the site. Large communal silos for storing and desiccating fish have been found at Cerro de Oro, indicating the possible controlled access to marine products such as fish and seabird guano. Products stored in these silos would be part of the exchange or redistribution system at Cerro de Oro rather than part of the daily domestic economy. The fact that some crops had higher $\delta^{15}N$ values than others suggest that different groups at the site may have had variable access to different types of fertilizers.

Relatively high δ^{15}N values were also observed in some of the C_3 grasses that usually are understood to be non-cultivated or wild plants, suggesting that these also received supplement nitrogen from fertilizers. Relatively high δ^{15}N values were found for C_3 grasses such as *Gynerium sagittatum* (+12.3 ± 7.1 ‰) and *Typha angustifolia* (+15.4 ± 3.0 ‰). Wild grasses of the genus *Cyperus* had the lowest δ^{15}N values of any non-leguminuous plant taxa (+8.9 ± 2.4 ‰; Figure 5.8), As discussed in chapter 3, δ^{15}N values tend to be higher in arid climates where water availability and precipitation is lower (Handley et al. 1999), but these are lacustrine plants that also grow within the irrigation channel margins, so the plants should not be water-stressed. The relatively low δ^{13}C values recorded for these types of plants also does not suggest water stress. An alternative explanation for the high δ^{15}N values in wild C_3 grasses could be the addition of fertilizers. These plants tend to grow naturally without human management. The addition of fertilizers to wild grasses may reflect the importance of these species in the Cerro de Oro economy for basketry making and roof construction. Cerro de Oro settlers may have considered plants such as *Typha angustifolia,* used to make basketry, important enough to provide them with supplemental fertilizers to increase yields. Santana-Sagredo et al. (2021) also observed relatively high δ^{15}N values in wild plants in the Atacama Desert, including legumes, and attributed these either to intentional fertilization or incidental fertilization.

Intensive farming means an increase in labour and/or capital inputs to an area of land in order to increase or maintain crop yield production per unit of land (McClatchie 2014). One way to achieve higher crop yields is through fertilization. Fertilizing can be completed with different kinds of natural fertilizers, such as camelid dung and seabird guano, which add nitrogen to the soil. There are differences between the amount of nitrogen provided by different types of natural fertilzers. Camelid dung has lower amounts of nitrogen than seabird guano, due to the kind of nitrogen excretion that mammals have compared to birds. Seabirds also consume marine resources, resulting in their excrement to provide higher δ^{15}N values than camelids, which consume C_3 and C_4 plants. More specifically, camelid dung can increase plant nitrogen values by a moderate amount (1.8 to 4.2 ‰) and seabird guano can increase plant nitrogen values by a substantial amount (11.3 to 20.0 ‰) (Szpak et al 2012a). About 3 km away from Cerro de Oro there are different forms of coastline. There are sandy and rocky coasts with inlets and outlets, islands, rocky outcrops, and crags. This is the case of Punta Centinela in Cerro Azul (Kubler 1948), which is the habitat of species such as the guanay cormorant (*Phalacrocorax bougainvillii*), the Peruvian Booby (*Sula variegata*) and the Peruvian Pelican (*Pelecan*us thagus), all of them guano-producing birds. Bone remains of these marine birds represent around the 30% of the MNI of faunal remains recovered at Cerro de Oro (González Gómez de Agüero 2019). Camelids represent around the 20% of MNI of faunal remains. Many of the camelid bones bear cutmarks, and camelid dung and corrals have also been found at the site (González Gómez de Agüero 2019). Therefore, both sources of fertilizer were available in the area. This suggests that both camelid dung and seabird guano could be easily obtained and used to fertilize crops. The use of fish carcasses as fertilizers should not be discounted as the site is close to the coastline. Anchoveta (*Engraulis ringens*) and other similar small fishes (González Gómez de Agüero 2019) and large silos to store, salt and desiccate fish (Fernandini 2019) were found at the site. As presented in chapter 2, this kind of fertilization was described by Cieza de León (1995 [1553]). An enrichment in ^{15}N of up to 8 ‰ to 17 ‰ in has been found in an experimental cultivation of beans with cod fish carcasses (Gröcke et al. 2020). Therefore, this practice of fertilization should be also taken into account as a possible explanation.

To have a better understanding of the fertilization practices at the archaeological site of Cerro de Oro, *Zea mays* grain δ^{15}N values from this research were compared with those presented by Szpak et al. (2012b) for field-grown maize fertilized with camelid dung and seabird guano (Figure 5.9). Cerro de Oro *Zea mays* δ^{15}N values fall between the maize fertilized with camelid dung and seabird guano. It is, however, difficult to determine which fertilizer was used in each crop as higher amounts of fertilizer being applied can result in higher plant δ^{15}N values for the same type of fertilizer (Szpak et al. 2012a). For example, a plant fertilized with a small amount of guano might be isotopically very similar to a plant fertilized with a large amount of camelid dung. Moreover, camelids producing dung at Cerro de Oro, might have had diets with higher δ^{15}N values than the camelids used in the modern study performed by Szpak et al. (2012b). This would be the case if camelids were being fed with fertilized crops or agricultural by-products. On the other hand, composting the camelid dung, can increase the δ^{15}N values (Choi et al. 2017). Modern expected δ^{15}N ranges for fertilizers cannot be directly applied, but the general patterns of seabird guano-fertilized plants having higher δ^{15}N values than camelid dung-fertilizer plants should apply; camelid dung -fertilized plants should also still have higher δ^{15}N values than unfertilized plants. Cerro de Oro plant δ^{15}N values generally coincide with the widespread use of fertilizers such as camelid dung and fish carcasses and those plants with much higher δ^{15}N values could be caused by the use of seabird guano, although distinguishing between the different types of fertilizers that may have been used requires more isotopic data, such as the analysis of camelids and fish remains from Cerro de Oro. Sulfur isotope analysis of the plant remains offers one possible means of clarifying this issue. Seabird guano and marine fish carcasses both impart high δ^{34}S values on plants when used as a fertilizer (Gröcke et al. 2020; Szpak et al. 2019). Camelid dung fertilization should not cause high δ^{34}S values in plants unless the camelids themselves had diets with high δ^{34}S values. Accordingly, high δ^{34}S values would not eliminate any of these three possible fertilizers, but high δ^{15}N values associated with low δ^{34}S values would eliminate fish carcasses and seabird guano as possibilities.

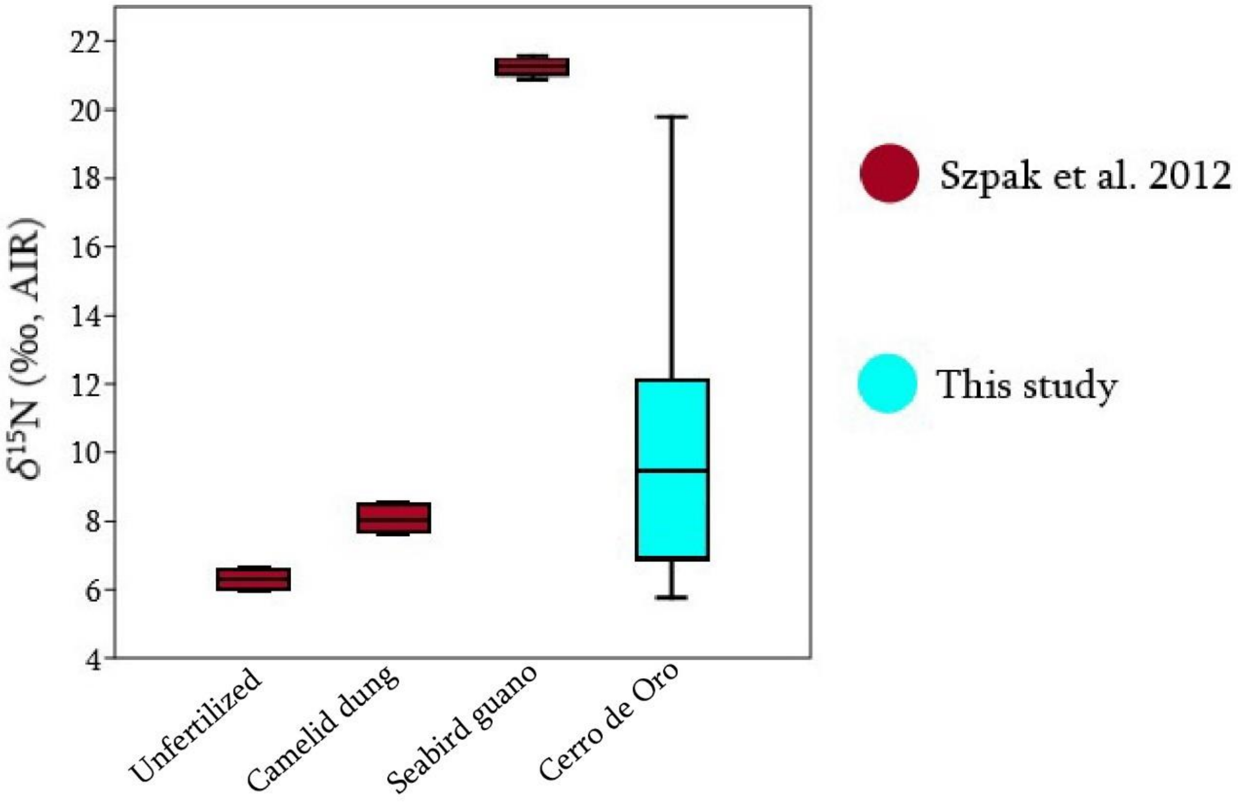

Figure 5.9. Comparison of δ^{15}N between different experimental maize fertilized with seabird guano and camelid dung from (Szpak et al. 2012b) and Cerro de Oro samples.

As discussed previously, water availability can impact plant δ^{15}N values. Specifically, plant δ^{15}N values can increase in hyper-arid, non-irrigated, coastal contexts (Craine et al 2009). Therefore, since the site of Cerro de Oro is within an arid region, the high δ^{15}N values of the plants could be reflecting aridity, rather than fertilization practices at the site. If this was the case, a positive correlation should be found between δ^{15}N and δ^{13}C values of C_3 plants. This means that with water stress plants tend to have higher δ^{15}N *and* δ^{13}C values. No positive correlation was found in any of the C_3 plants compared in this study, with the exception of *Phaseolus* sp. (Table 5.4). It is important to point out, however, that a significant and stronger negative correlation was found for *Phaseolus lunatus*. In any case, there is no evidence for a consistent pattern of high δ^{15}N values being accompanied by high δ^{13}C values for C_3 plants at Cerro de Oro. This pattern suggests that the overall high δ^{15}N values are caused by fertilization rather than water stress.

Table 5.4. Correlations (Spearman's ρ) between δ^{13}C and δ^{15}N values for taxa with more than 10 analyzed samples at Cerro de Oro. Values in boldface indicate statistically significant correlations.

Taxonomic name	***n***	**Spearman's ρ**	***p***
Arachis hypogaea	21	0.06	0.79
Canna indica	13	0.30	0.32
Cannavalia sp.	31	−0.19	0.28
Capsicum sp.	11	−0.29	0.38
Cucurbita maxima	41	0.12	0.46
Cyperus sp.	17	0.14	0.59
Gossypium barbadense	30	−0.06	0.75
Inga feuilleei	26	−0.11	0.59
Lagenaria siceraria	11	0.19	0.59
Phaseolus lunatus	**40**	**−0.40**	**0.01**
Phaseolus sp.	**52**	**0.29**	**0.04**
Phaseolus sp. Sub. nunas	18	−0.04	0.86
Pouteria lucuma	48	0.19	0.19
Psidium guajava	25	−0.09	0.65
Schinus molle	10	−0.21	0.55
Typha angustifolia	12	0.25	0.43

5.4.1. δ^{15}N values in Legumes

As outlined in chapter 3, legumes are N_2-fixing plants that form a symbiotic relationship with nitrogen-fixing bacteria. These plants take up atmospheric N_2 (δ^{15}N ~0 %) so they tend to have low δ^{15}N values compared with other plants, typically around 0 ‰ (Szpak et al. 2014). However, the average δ^{15}N value for the legumes at Cerro de Oro was +3.7 ± 2.9 ‰. Most of the *Phaseolus* samples had slightly higher δ^{15}N values than expected for legumes, which may indicate that these plants received some supplemental nitrogen from fertilizers such as camelid dung, seabird guano, or fish offal (Figure 5.10). Relatively high δ^{15}N values were also observed for the legumes *Cannavalia* sp. and *Inga feuilleei* (Figure 5.8). The sample sizes for *Caesalpinia spinosa* and *Prosopis pallida* were small and it was therefore not possible to determine if the isotopic compositions obtained here represent the true range of variation in δ^{15}N for these plant species at Cerro de Oro. Nevertheless, both taxa have δ^{15}N values that were higher than expected for legumes (Figure 5.10). Santana-Sagredo et al. (2021) also observed high δ^{15}N values for *Prosopis* in northern Chile with several specimens having δ^{15}N values above +20 ‰.

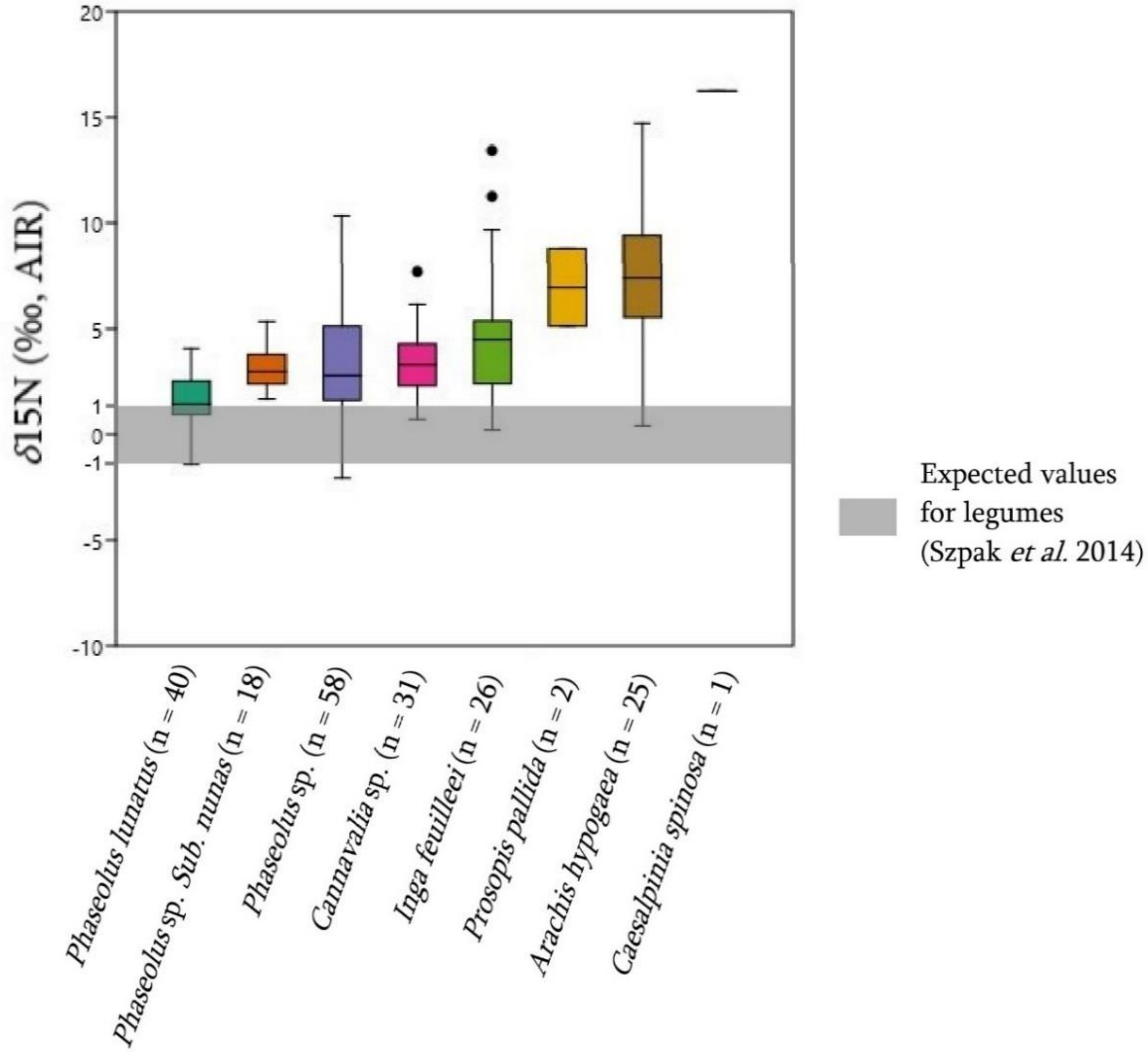

Figure 5.10. Comparison of taxonomic variation in mean δ^{15}N values for legumes from Cerro de Oro.

Finally, peanuts (*Arachis hypogaea*) had higher δ^{15}N values than the other legumes analysed, with an average δ^{15}N of +7.5 ± 3.0 ‰. This taxon may have been more intentionally fertilized (relative to the other leguminous crops) or grown in rotation with fertilized non-leguminous plants, when some fertilizer-derived nitrogen may still have been available.

As explained before, legumes are expected to have δ^{15}N values of ≈0‰, as they acquire their nitrogen from atmospheric N_2 with little to no fractionation (Szpak et al. 2014). However, more variability is expected for archaeological samples as cultivation was probably much more variable than it is nowadays. While we can assume than most of the legumes at Cerro de Oro were not being fertilized or were being minimally fertilized, the peanut (*Arachis hypogaea*) has δ^{15}N values of 7.5 ± 3.0 ‰, which is higher than what is normally seen for legumes. These high δ^{15}N values could be caused by two different cultivation practices: shifting cultivation/crop rotation and companion planting.

Shifting cultivation involves land cultivation and then abandonment to leave it fallow and allow the soil to regenerate to avoid soil exhaustion (McClatchie 2014). While crop rotation involves altering the types of plants grown on the same land with the intention of discouraging the development of diseases that affect a specific type of crop and avoiding soil nutrient depletion. Both practices can also be used together. Given their relatively high δ^{15}N values, it is possible that peanuts were planted in fields where other crops had been previously fertilized. Rotating the peanut, a legume, with other crops may have helped those other crops receive nutrients. In modern agricultural settings, the rotation of peanuts with other crops occurs especially with grasses such as maize, and can occur every three years (Dwyer and Sandhu 2000). Peanut has proven to create a particularly successful symbiotic relationship when rotated with maize. This occurs as peanut has a non-rhizobial nodule bacterium that can increase plant growth by creating endophytic bacteria that interact with different plant species (Ibañez et al. 2014). The high δ^{15}N values observed for maize relative to many other crops (suggesting significant fertilization) further suggests a maize-peanut rotation in some of these fields. Crop rotation favours the availability of residual fertilizer-derived nutrients, which has been shown to be more beneficial to peanuts relative to direct fertilizer application (Pedelini 2012).

Companion planting consists of planting more than one crop in the same field at the same time. The two plants are sufficiently close to each other for interspecific competition or complementation. This improves the control of spontaneous vegetation or weeds and can act as a pesticide. In environments with high susceptibility to wind erosion, the height of the maize protects the peanut (Morla et al. 2014). Therefore, another possibility for the higher δ^{15}N values of peanuts at Cerro de Oro is that peanuts were planted with other crops that were being fertilized. The most common form of companion planting in this part of the world is the bean-maize-squash triad (Bonavia et al. 2009; Sauer 1952). This symbiotic relationship helps the growth of all three species. This also works for high altitude tubers and rhizomes (Leon 2014). These three plants complement each other in the following ways: maize grows high and requires sunlight and moisture; beans climb their stalks to access sunlight and their roots contain nitrogen-fixing bacteria; and squash tend to border the base of these two plants. The successful symbiotic relationship between maize and peanut and the contribution of nitrogen from this legume to maize has been demonstrated by Dakora et al. (1987). This type of relationship could also occur with *Cannavalia* sp. and maize, whose association has been proven to be successful (Quiroga-Madrigal et al. 2006).

To summarize, maize and C_3 non-leguminous crops were being fertilized at Cerro de Oro. Peanuts were probably the most important legume as a companion species to maize, to a greater extent than beans. Beans, seem to have been growing separately and were not fertilized or minimally fertilized, based on their low δ^{15}N values. Most of the legumes at Cerro de Oro still had δ^{15}N values around 4 ‰ and were therefore higher than expected. When supplied with organic fertilizers, legumes tend to have δ^{15}N values similar to non-legumes (Szpak et al. 2014). While the δ^{15}N values of the legumes were higher than expected, they were still lower than the non-legumes at the site (Figure 5.8). This means that probably beans and other legumes were being rotated and growing after fertilized plants while peanuts were part of a companion planting system. This lack of direct nitrogenous fertilization for most of the legumes indicates knowledge about the needs of specific taxa with respect to plant nutrition and suggests a concerted effort by the inhabitants of Cerro de Oro to increase crop yields with minimal additional inputs.

During the EIP, numerous Andean communities, especially on the coast, occupied large territories and in some cases formed states (Ikehara 2019). These political developments were accompanied by agricultural intensification and extensification (Ikehara 2019), although direct evidence for intensification in the way of crop fertilization has ben lacking. The use of natural fertilizers during the EIP underscores the importance of increasing crop yields, likely to support growing populations and the political economies of the time. This type of agricultural practice, together with the implementation of extensive irrigation systems, allowed for population growth and the existence of large population centres (Ikehara 2019). Cerro de Oro is one of the best examples of one of these large population centres that emerged during the EIP. It brought together different populations from the Cañete and other valleys as evidenced by the diverse range of material culture traditions found at the site. The construction of this urban center was facilitated by the production of agricultural resources, which aided by the use of fertilizers and irrigation systems.

The communities inhabiting the lower Cañete Valley during the EIP, including Cerro de Oro, had a mainly agricultural economy complemented by marine fishing and camelid pastoralism. Other smaller population centers, closer to the coast and with a primarily maritime economy, could have provided Cerro de Oro with the marine resources found at the site, including fish and, based on the isotopic evidence from the plant remains, seabird guano. The use of camelid dung as a fertilizer was likely an important part of the local economy, consistent with the use of corrals in domestic spaces within the densely populated settlement of Cerro de Oro. Additional research focused on the nature of camelid husbandry at Cerro de Oro would be useful in assessing to what extent camelids were raised locally and what kinds of diets these camelids had.

Within the context of the agricultural economy at Cerro de Oro, maize seems to have been the most important crop, not just in terms of abundance at the site but also in terms of the high amount and different types of fertilizer applied. Maize had the most variable, but also the highest, $\delta^{15}N$ values suggesting the use of both camelid dung to seabird guano as fertilizers. Therefore, this crop was probably the staple of human diet at Cerro de Oro and an important component in the emergence of Cerro de Oro as a regional centre.

The presence of specialists and artisans during this period came with a division between the urban and the rural. Cerro de Oro, a place that brought together thousands of families and diverse groups, probably had an economy of mutual dependence with rural (agricultural) and coastal (fishing) productive nuclei, many of them probably self-sufficient. This subsidiary relationship with the other smaller settlements in the rest of the valley still generates many unknowns about the sociopolitical organization of Cerro de Oro and its role in obtaining, storage and redistributing products.

5.4.2. Agricultural Extensification at Cerro de Oro: Irrigation

While variation in $\delta^{15}N$ was substantial in almost every taxon, there was considerably less variation within taxa for $\delta^{13}C$. Most of the taxa had $\delta^{13}C$ values within the expected ranges for C_3 and C_4 plants. Constant water irrigation will tend to promote the stomatal opening, allowing non-restricted CO_2 diffusion into the leaf. This means less discrimination against ^{13}C and therefore, lower $\delta^{13}C$ values. In addition to irrigaton, low $\delta^{13}C$ values for riparian and lacustrine taxa such as *Cyperus* sp. or *Typha angustifolia*, may be the results of growing in aquatic environments like *La Encantada* lagoon near Cerro de Oro.

Extensive agriculture seeks to increase productivity through the cultivation of large extended fields that receive relatively little labour (McClatchie 2014) and can be associated with the movement of people and a reconfiguration of the landscape, extending the arable lands. Extensification is usually associated with higher output per capita (McClatchie 2014), and therefore larger settlements. Practices such as irrigation are often considered mechanisms of agricultural intensification because it increases crop productivity. However, irrigation systems are also a way to expand arable lands and are a way to ensure water supply, and can therefore be also considered an extensification strategy (Styring et al. 2017). The presence of both a huge irrigation system occupying the whole alluvial fan in the lower valley and the access to natural fertilizers indicates that agriculture of Cerro de Oro could be both intensive and extensive. The lack of precipitation may have made extensification via irrigation mandatory, while intensification via fertilization came later, perhaps as a way to increase yields to feed the populace of this growing, monumental settlement. The relationship among the development of an irrigation system, the climatic uncertainty caused by ENSO and the construction of Cerro de Oro, proposed by Fernandini (2018b) has been described in chapter 2.

Variation in plant $\delta^{13}C$ is sensitive to water management practices such as irrigation. $\delta^{13}C$ values can also indicate agricultural responses to climatic uncertainty. As explained in chapter 3, environmental conditions affect $\delta^{13}C$ values in C_3 plants. In contexts where climatic uncertainty, such as flooding or drought, has been previously documented we can expect relatively low or high $\delta^{13}C$ values, respectively (Styring et al. 2017). If C_3 crops growing in arid environments have $\delta^{13}C$ values that are not especially high, this may suggest that plants were being supplied with water through irrigation (Styring et al. 2017).

As seen in Figure 5.11, $\delta^{13}C$ values for cotton (*Gossypium barbadense*) (−22.40 ± 1.38 ‰) are significantly higher than the average for C_3 crops (−25.32 ± 1.61 ‰) (Mann Whitney U test; $p < 0.001$). This suggests that cotton grew in naturally drier areas or received less water through irrigation relative to other crops. Cotton is usually grown during the summer in arid and semiarid regions where water availability is often limited. Regardless of whether it is irrigated or not, cotton is often exposed to conditions of restricted water availability. This has been suggested to adversely affects both yield and lint quality (Saranga et al. 2003; Saranga et al. 1998).

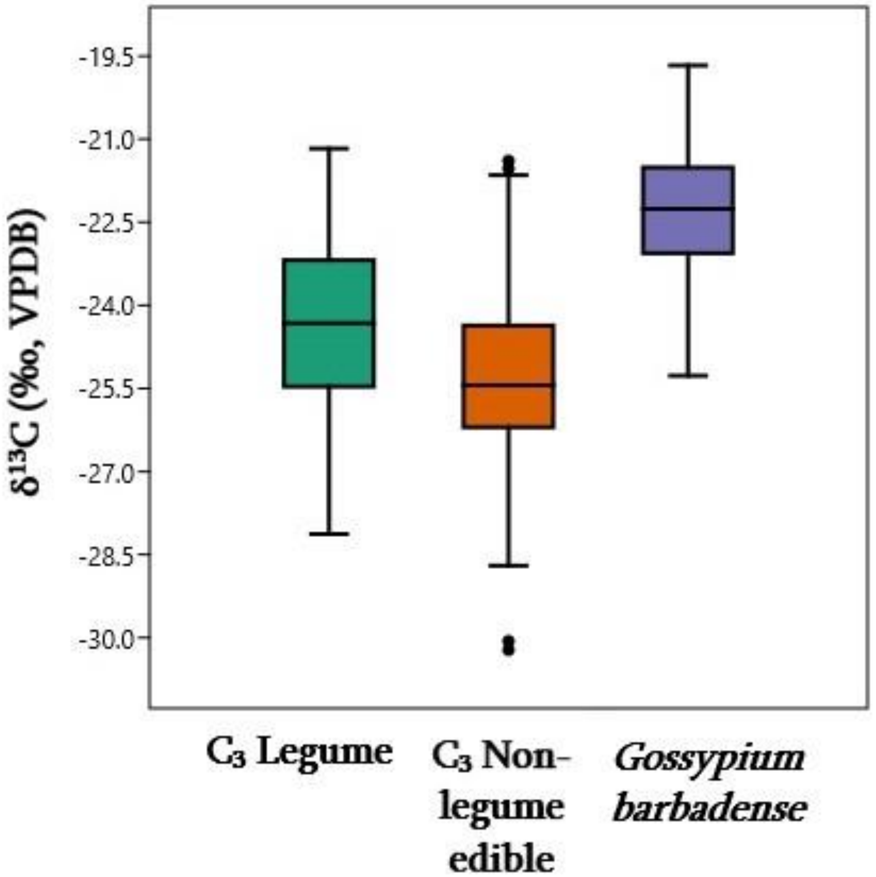

Figure 5.11. Comparison of δ^{13}C values among C_3 legumes, C_3 non-legume edible plants, and cotton (*Gossypium barbadense*) at Cerro de Oro.

While cotton is often exposed to water stress, it is a crop that generally uses a lot of water. That is why, efforts have been made to reduce agricultural water use (i.e., deficit irrigation or water stress, meaning the application of water below full crop-water evapotranspiration requirements (Fereres and Soriano 2006)) in cotton (Hafiz Shahzad et al. 2021; Sahito et al. 2015; Saranga et al. 2003; Saranga et al. 1998). As indicated by local farmers, (e.g., Victor Prado Palomino, personal communication, June 27, 2022), this type of irrigation is still being used in modern agriculture in the Middle and Lower Cañete valley. This means irrigating after long periods of water stress, up to a month between irrigation, assuring the growth of tissues such as stems and leaves and then intensively irrigating during the growth of plant fruits. Imposing water stress at certain developmental periods could benefit the yield and quality of some crops (Fereres and Soriano 2006). This type of irrigation is not suitable for every species and growth stage. For example, this approach does not appear to work for maize during the grain filling period (Pandey et al. 2000). This type of irrigation assures productivity even in context of climatic uncertainty, low water availability and recurrent droughts, as happened in Cerro de Oro, while maintaining or even improving fruit productivity.

Cotton is more often intensively irrigated during blooming (Lizárraga Travaglini and Caldas Cueva 2020). Studies in Xinjiang, China, an arid area, suggest to decreasing the water and nitrogen supply before the full flowering stage, but increasing the amount of water and nitrogen applied at the middle and later growth stages as a high-yield, high-efficiency cultivation technique (Hongzhi et al. 2017). Different cotton genotypes have different responses to irrigation and WUE (Saranga et al. 2003; Saranga et al. 1998). Therefore, a number of different scenarios could explain the high δ^{13}C values in *Gossypium barbadense* at Cerro de Oro.

The first explanation is that farmers at Cerro de Oro found a balance between maximizing crop yields and minimizing water inputs. As it does today, the Cerro de Oro irrigation system involved the opening and closing of subsidiary ditches to the main canals. This means that different crops could have been receiving variable amount of irrigation water, in some cases under a deficit irrigation system. Thus, the high δ^{13}C values in cotton could reflect a successful deficit irrigation, demonstrating the extensive agricultural knowledge available at the time.

However, this type of irrigation system does not explain why the reproductive tissues and flowers were also characterized by relatively high δ^{13}C values. If more irrigation water was supplied during the growth of these tissues, they should have relatively low δ^{13}C values, but this is not the case (Table 5.1). This discrepancy could be explained by the way in which the tissues are formed. Leaves are formed during the period when the plant is exposed to less irrigation, and these leaves are a carbon sink. When tissues form during flowering such as bolls and seeds, irrigation is more intense. However, the carbon they receive during their formation does not only come from CO_2 acquired while plant reproductive tissues are growing, but also from carbon sinks in the plant, such as the leaves (Badeck et al. 2005). Therefore, the δ^{13}C values of these tissues could be the product of the mixture of earlier stages of growth when water availability was low and intensive irrigation when blowing. When post-photosynthetic fractionation of carbon isotopes between plant organs occurs, the tissues that form later will be depleted in ^{13}C (Badeck et al. 2005). The data therefore suggest that cotton was grown in drier conditions (i.e. deficit irrigation) than other crops and there is no direct evidence to suggest a pulse of watering through irrigation during the later stages of growth, but such a signal may be obscured because of the way in which organic matter is remobilized within the plant during growth.

6. Conclusions

When performing stable isotope analysis, especially for the purpose of reconstructing human diets, it is common to read the cliched but true phrase: "we are what we eat". While this is one of the basic principles of stable isotope analysis, it could be more accurately phrased "we are what we eat and how we produce and eat it". In other words, we cannot always make assumptions about the stable isotope values of foods because these can vary between places, periods, and with cultural practices. Increasingly, it has been suggested that in order to make accurate interpretations of past human diet using stable isotopes, one should analyse a sample of the foods that those humans may have consumed, in other words a sample that is as regionally- and temporally-specific as possible (Santana-Sagredo et al. 2021; Szpak and Chiou 2020; Szpak et al. 2013). Not understanding the isotopic variation in possible foods can lead to misinterpretations. For example, high δ^{15}N values in human tissues could be attributed to a high reliance on marine foods. However, these high δ^{15}N values might also be produced by high plant δ^{15}N values as occurs in arid environments and with fertilization. Thus, the consumption of fertilized plants can be confused with a marine diet on the basis of isotopic evidence. Knowing the isotopic compositions of plants at the Cerro de Oro allows for more accurate interpretations of human and animal diet on the basis of stable isotope data, as discussed in Section 5.3. Ideally, analysing the isotopic compositions of botanical and zooarchaeological remains from archaeological sites should be a requirement for reconstructing paleodiets.

Through the stable carbon and nitrogen isotopes analysis of desiccated botanical macroremains this thesis has advanced our knowledge about agricultural practices at

Cerro de Oro. More generally, the results of this thesis have also contributed to a larger debate surrounding the reliability of stable isotope measurements of charred and desiccated macrobotanical remains. A comparison between charred and desiccated maize cobs have supported the assertions of Szpak and Chiou (2020) that stable carbon and nitrogen isotope measurements of dissected botanical remains can be reliable. In this study, using a large number of specimens of charred and desiccated maizes from the same site, there was no significant difference in the δ^{15}N values. This is an important finding as it lends further support to the idea that using desiccated botanical remains isotopic analysis is viable, creating a wide range of opportunities for future studies in the Andes. Moreover, the analysis of different tissues of the same species (e.g., *Inga feuilleei*) or even of the same individual (e.g., *Gossypium barbadense*), also produced similar δ^{15}N values, even when the N% was different between tissues. While additional studies are required with botanical material from other sites, these two lines of evidence both suggest that stable isotope values obtained from desiccated plant remains can be reliable. With respect to sample pretreatment, this thesis demonstrated the utility of sonication to clean samples from dust and soil particles.

As for δ^{15}N values in plants at Cerro de Oro, we found a great amount of variability. This variability is much higher than has been observed in modern plants sampled from the Andes, further emphasizing the importance of regionally- and temporally-specific isotopic baselines for palaeodietary studies. Although the δ^{15}N values were highly variable, they were also relatively high, suggesting the use of natural fertilizers such as camelid dung, fish carcasses, and seabird guano. The most isotopically variable taxon was maize, although this may simply be a product of the fact that it was also the most abundant taxon included in this study. Very high δ^{15}N values were observed for some maize samples that could be linked to the use of seabird guano, but in general the values were more consistent with the use of camelid dung and/or fish carcasses as fertilizers. The presence of large numbers of guano birds, the large variety and quantity of fish taxa, and camelid bones and corrals at the site suggest that the use of all three types of fertilizers may have occurred at the site. Overall, maize had the highest δ^{15}N values, on average, of any of the plant taxa examined. This suggests an emphasis on increasing maize yields relative to other crops, as maize seems to have received the highly potent seabird guano fertilizer more frequently than other crops. The abundance of maize at Cerro de Oro, combined with these high δ^{15}N values could be linked with a period of population growth and gathering in one monumental site. An intensive production of maize using fertilizers was one of the backbones of Cerro de Oro’s successful emergence and development. In general, the non-leguminous C_3 plants had δ^{15}N values that also suggested that crops were fertilized, highlighting some such as *Pouteria lucuma, Psidium Guajava, Canna indica*, *Gossypium barbadense* or *Lagenaria Siceraria* that had particularly high δ^{15}N values. Some wild C_3 grasses such as *Typha angustifolia*, also presented high δ^{15}N values that could be linked to the use of fertilizers. This is important as these riparian plants tend to grow naturally, however, it seems that in Cerro de Oro economy, the use of these plants for basketry and construction was important enough to include them in the intensive agricultural system, suggesting some degree of human management for this species. As for leguminous plants, the δ^{15}N values reported were slightly higher than those reported in previous studies for modern plants sampled in the Andes, but not as high as non-leguminous taxa at Cerro de Oro. These slightly higher δ^{15}N values in beans and other legumes suggest that these plants were being rotated with fertilized plants. Peanuts (*Arachis hypogaea*) had higher δ^{15}N values than expected and had the highest δ^{15}N values among all of the legumes (7.5 ± 3.0 ‰). These high δ^{15}N value suggest that peanuts were part of a companion planting system, possibly with maize that was heavily fertilized.

Regarding δ^{13}C values, considerably less variation within taxa was found. Most of the taxa had δ^{13}C values within the expected ranges for C_3 and C_4 plants. Irrigation played a vital role in Cerro de Oro agriculture, as it did in the coastal river valleys all along the Peruvian coast. Cotton (*Gossypium barbadense*) had δ^{13}C values that were higher than the rest of the C_3 crops. These δ^{13}C values could reflect deficit irrigation practices in the vegetative phase of cotton as a way to increase productivity.

Therefore, Cerro de Oro agricultural knowledge seems to have been widespread. Intensive agriculture was practice by adding manure to most of the crops that required nitrogenous fertilizers, but with minimal inputs of fertilizers to the legumes, with the exception of peanuts. The inhabitants of Cerro de Oro may have used this knowledge to create symbiotic relationships between crops such as companion planting between peanuts and maize. The fertilizers that they used may have included camelid dung, fish carcasses, and seabird guano. In most cases it is not possible to link a single plant δ^{15}N value to a particular type of fertilizer, but some of the very high δ^{15}N values observed for some of the plants, particularly maize, likely indicate the use of seabird guano as a fertilizer. The other δ^{15}N values, while high, may be the product of any of the fertilizers mentioned previously.

Regarding extensive agriculture, the emergence of Cerro de Oro seems to be related to the expansion of irrigation canals and therefore with the increase of arable lands and crop production. An increase in labour in the agricultural economy was probably necessary to feed the monumental settlement that was being formed in Cerro de Oro. Deficit irrigation, could be also another agricultural practice developed in an area and time where climatic uncertainty was prevailing. The irrigation system in the Cañete Valley was then a way to gather a communal effort to feed an increasing population but also to face El Niño effects, creating a large settlement far from the river floods but surrounded by water brought by irrigation. This collective work required the effort of different groups in different parts of the valley. No sign of hierarchical organization has been found at Cerro de Oro (Fernandini 2018b). Irrigation was very important for the northern neighbours in Lima and a lack of water was the main problem for the southern neighbours in Nasca. The successful development of an irrigation system for an intensive and extensive agriculture in the Cañete valley, led by the Cerro de Oro population, seems to have been appealing to both contiguous groups. This is reflected in how Cerro de Oro experienced significant cultural development characterized by the emergence of local material culture, punctuated by foreign influences from traditions such as Lima and Nasca (Fernandini 2015a, 2015b, 2018a, 2018b, 2019, 2020). Probably the different groups living at Cerro de Oro were tied with both Lima or Nasca.

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8. Appendix

Appendix 1: Occupational sequence of the Cerro de Oro phase based on ^{14}C dates and changes in architecture. **Source:** Fernandini 2022.

RADIOCARBON DATING ARCHAEOLOGICAL PROJECT OF CERRO DE ORO		
Sample	**2 sigma 95%**	**Period**
Guarco-Inca		
Stem	Cal AD 1436-1502	Guarco-Guarco Inca
Stem	Cal AD 1457-1504 Cal AD 1590-1616	
Stem	Cal AD 1425-1504	
Abandonment		
Stem	Cal AD 860 to 985	Cerro de Oro
Stem	Cal AD 775 to 815 Cal AD 840 to 985	
Stem	Cal AD 773-823 Cal AD 831-883	
Stem	Cal AD 658-881	
Tooth enamel	Cal AD 676-773 Cal AD 825-826 (0.001)	
Phase 5 -Quincha walls		
Stem	Cal AD 770 to 900 Cal AD 925 to 965	Cerro de Oro
Pod	Cal AD 773-820 Cal AD 834-893(0.639) Cal AD 941-947	
Stem	Cal AD 768-874	
Stem	Cal AD 768-891	
Phase 4-Remodeling 2		
Stem	Cal AD 690 to 735 Cal AD 765 to 890	Cerro de Oro
Stem	Cal AD 682-743 Cal AD 759-859	
Stem	Cal AD772-824 Cal AD 830-883	
Stem	Cal AD 670 to 775	

	Cal AD 820 to 835	
Stem	Cal AD 657-690 Cal AD 702-721 Cal AD 730-765	
Phase 3-Remodeling 1		
Stem	Cal AD 598-682 Cal AD 746-756	Cerro de Oro
Maize Cob	Cal AD 689-734 Cal AD 764-864 Cal AD 867-873	
Stem	Cal AD 600-680	
Phase 2- Post- Wall		
Stem	Cal AD 580 to 650	Cerro de Oro
Stem	Cal AD 630-684	
Stem	Cal AD 652-690 Cal AD 731-765	
Stem	Cal AD 580 to 650	
Tooth enamel	Cal AD 645-675	
Phase 1- Sterile		
Stem	Cal AD 605 to 615 Cal AD 630 to 675	Cerro de Oro
Stem	Cal AD 525 to 635	
Maize Cob	Cal AD 584-640	
Reed	Cal AD 594-645	

Appendix 2: Isotopic and elemental compositions for each sample

Sample ID	Species	Element	$\delta^{13}C_{VPDB}$	$\delta^{15}N_{AIR}$	wt% C	wt% N	$C{:}N_{atomic}$
15091	*Arachis hypogaea*	Pod	-26.11	9.6	42.77	0.87	57.13
15092	*Arachis hypogaea*	Pod	-23.06	8.3	43.95	0.96	53.14
15093	*Arachis hypogaea*	Pod	-24.58	11.0	44.42	0.94	55.21
15094	*Arachis hypogaea*	Pod	-23.01	9.9	46.60	0.88	61.90
15095	*Arachis hypogaea*	Pod	-23.01	9.2	43.75	0.91	55.99
15096	*Arachis hypogaea*	Pod	-25.14	14.70	46.14	0.60	89.46
15097	*Arachis hypogaea*	Pod	-26.03	6.3	38.60	1.03	43.77
15098	*Arachis hypogaea*	Pod	-25.75	4.90	42.39	0.81	61.02
15099	*Arachis hypogaea*	Pod	-24.70	11.30	47.55	1.29	42.99
15100	*Arachis hypogaea*	Pod	-25.07	9.0	39.75	0.85	54.31
15101	*Arachis hypogaea*	Pod	-24.74	5.3	43.75	0.75	68.25
15102	*Arachis hypogaea*	Pod	-26.08	6.4	44.54	0.73	71.31
15103	*Arachis hypogaea*	Pod	-24.47	8.5	43.37	0.71	70.87
15104	*Arachis hypogaea*	Pod	-23.88	7.1	44.92	0.82	63.57
15105	*Arachis hypogaea*	Pod	-26.28	6.30	46.26	1.00	53.95
15106	*Arachis hypogaea*	Pod	-26.98	4.6	41.48	1.18	41.00
15107	*Arachis hypogaea*	Seed	-24.39	0.42	39.74	5.50	8.43
15108	*Arachis hypogaea*	Pod	-24.32	7.4	46.34	0.98	55.15
15109	*Arachis hypogaea*	Pod	-22.61	3.48	47.24	0.98	56.21
15110	*Arachis hypogaea*	Pod	-25.01	8.3	38.89	0.96	47.44
15111	*Arachis hypogaea*	Pod	-24.13	5.8	40.57	1.81	26.21

15112	*Baccharis sp.*	Stem	-22.95	25.20	48.08	0.42	133.51
15113	*Bunchosia armeniaca*	Seed	-25.52	12.08	44.33	0.97	53.30
15114	*Caesalpinia spinosa*	Pod	-24.32	16.24	45.44	1.56	34.06
15115	*Canna indica*	Rhizome	-21.93	16.11	41.60	1.84	26.33
15116	*Canna indica*	Rhizome	-23.95	7.39	37.96	0.77	57.50
15117	*Canna indica*	Leaf	-26.64	11.96	41.46	2.15	22.52
15118	*Canna indica*	Leaf	-25.97	14.70	43.99	2.77	18.54
15119	*Canna indica*	Leaf	-24.77	13.41	38.03	3.09	14.37
15120	*Canna indica*	Rhizome	-23.30	32.83	41.35	0.88	54.83
15121	*Canna indica*	Leaf	-23.48	12.97	37.98	2.50	17.71
15122	*Canna indica*	Leaf	-25.48	9.56	47.36	2.20	25.05
15123	*Canna indica*	Stem	-24.87	11.74	43.52	1.22	41.45
15124	*Canna indica*	Rhizome	-25.96	11.09	42.79	0.52	95.99
15125	*Canna indica*	Rhizome	-24.62	9.69	36.50	0.61	69.55
15126	*Canna indica*	Rhizome	-23.59	14.91	34.14	2.27	17.51
15127	*Canna indica*	Rhizome	-25.68	20.33	45.94	1.40	38.27
15128.1	*Cannavalia* sp.	Pod	-25.43	2.73	35.24	0.73	56.65
15128.2	*Cannavalia* sp.	Seed	-24.81	4.25	38.95	1.73	26.26
15129	*Cannavalia* sp.	Seed	-22.28	3.61	43.81	5.18	9.86
15130	*Cannavalia* sp.	Seed	-21.17	3.30	40.61	2.65	17.87
15131	*Cannavalia* sp.	Seed	-23.19	2.55	42.90	2.87	17.44
15132	*Cannavalia* sp.	Seed	-22.93	1.61	42.93	3.56	14.06
15133	*Cannavalia* sp.	Seed	-23.38	1.54	42.51	3.39	14.61
15134	*Cannavalia* sp.	Seed	-21.64	2.33	41.32	2.51	19.22

15135	*Cannavalia* sp.	Seed	-24.29	1.75	42.85	3.19	15.68
15136	*Cannavalia* sp.	Seed	-23.48	1.70	42.13	2.29	21.43
15137	*Cannavalia* sp.	Seed	-25.48	6.15	43.17	4.39	11.48
15138	*Cannavalia* sp.	Seed	-22.92	4.23	43.36	4.24	11.93
15139	*Cannavalia* sp.	Seed	-25.49	2.62	40.01	1.50	31.13
15140	*Cannavalia* sp.	Seed	-23.15	3.96	40.50	2.11	22.43
15141	*Cannavalia* sp.	Seed	-24.21	5.80	41.58	2.80	17.30
15142	*Cannavalia* sp.	Seed	-25.81	4.04	45.60	5.65	9.42
15143	*Cannavalia* sp.	Seed	-24.39	1.20	41.84	2.41	20.26
15144	*Cannavalia* sp.	Seed	-23.83	2.87	39.56	1.77	26.08
15145	*Cannavalia* sp.	Seed	-23.95	4.33	41.90	2.93	16.68
15146	*Cannavalia* sp.	Seed	-23.70	0.73	42.68	3.07	16.21
15147	*Cannavalia* sp.	Seed	-24.66	4.08	43.18	2.77	18.19
15148	*Cannavalia* sp.	Seed	-26.58	4.28	42.99	1.50	33.42
15149	*Cannavalia* sp.	Seed	-24.17	5.48	42.68	1.46	34.18
15150	*Cannavalia* sp.	Seed	-24.29	4.73	42.94	3.32	15.09
15151	*Cannavalia* sp.	Seed	-24.81	7.70	42.36	2.61	18.93
15152	*Cannavalia* sp.	Seed	-23.22	5.48	41.21	2.14	22.42
15153	*Cannavalia* sp.	Seed	-23.33	2.87	41.26	1.91	25.25
15154	*Cannavalia* sp.	Seed	-25.01	2.91	41.08	1.13	42.37
15155	*Cannavalia* sp.	Seed	-24.88	2.68	40.87	2.95	16.15
15156	*Cannavalia* sp.	Seed	-25.75	2.18	40.72	2.84	16.75
15157	*Cannavalia* sp.	Seed	-24.42	3.32	41.71	1.52	32.00
15158	*Capsicum* sp.	Stem	-25.90	12.3	45.00	0.80	65.90

15159	*Capsicum* sp.	Stem	-27.04	6.4	42.71	1.02	48.79
15160	*Capsicum* sp.	Stem	-23.10	9.5	42.91	0.99	50.43
15161	*Capsicum* sp.	Peduncle	-28.06	17.9	42.94	1.47	34.13
15162	*Capsicum* sp.	Peduncle	-26.44	11.7	43.39	0.89	56.73
15163.1	*Capsicum* sp.	Peduncle	-26.58	10.75	45.62	2.01	26.47
15163.2	*Capsicum* sp.	Seed	-24.42	12.00	47.19	2.39	23.03
15164	*Capsicum* sp.	Peduncle	-28.70	12.30	44.03	1.15	44.65
15165	*Capsicum* sp.	Peduncle	-25.41	13.36	47.10	2.01	27.33
15166	*Capsicum* sp.	Fruit	-25.72	9.15	46.98	2.39	22.92
15167	*Capsicum* sp.	Peduncle	-27.59	11.25	48.74	2.41	23.59
15168	*Cucurbita maxima*	Seed	-26.10	8.31	57.80	5.55	12.14
15169	*Cucurbita maxima*	Seed	-25.88	9.20	58.15	4.91	13.82
15170	*Cucurbita maxima*	Seed	-27.02	10.55	56.41	4.73	13.92
15171	*Cucurbita maxima*	Seed	-26.64	9.15	56.67	3.99	16.55
15175	*Cucurbita maxima*	Seed	-25.45	7.75	47.73	4.66	11.95
15176	*Cucurbita maxima*	Seed	-24.15	7.09	50.38	3.26	18.05
15177	*Cucurbita maxima*	Seed	-23.83	12.41	53.00	5.99	10.31
15178	*Cucurbita maxima*	Seed	-26.82	10.75	44.50	5.23	9.93
15179	*Cucurbita maxima*	Seed	-23.32	11.31	42.97	4.73	10.61
15180	*Cucurbita maxima*	Seed	-27.45	11.97	51.82	4.68	12.90
15181	*Cucurbita maxima*	Stem	-24.96	6.48	46.39	1.23	43.98
15182	*Cucurbita maxima*	Peduncle	-25.88	2.98	47.69	0.80	69.43
15183	*Cucurbita maxima*	Peduncle	-22.19	10.20	48.48	1.01	55.91
15184	*Cucurbita maxima*	Peduncle	-25.34	14.36	48.32	0.66	85.38

15185	*Cucurbita maxima*	Peduncle	-24.84	13.47	50.06	0.89	65.33
15186	*Cucurbita maxima*	Peduncle	-25.82	11.46	48.25	0.84	66.61
15187	*Cucurbita maxima*	Peduncle	-26.60	11.51	49.13	0.72	79.40
15188	*Cucurbita maxima*	Seed	-25.93	11.74	47.73	5.73	9.72
15189	*Cucurbita maxima*	Seed	-27.14	9.90	42.59	4.03	12.34
15190	*Cucurbita maxima*	Seed	-26.00	11.02	53.56	6.45	9.68
15191	*Cucurbita maxima*	Seed	-25.63	10.83	43.87	5.30	9.65
15192	*Cucurbita maxima*	Seed	-26.08	11.09	40.54	4.51	10.49
15193	*Cucurbita maxima*	Seed	-26.32	8.64	48.29	4.99	11.28
15194	*Cucurbita maxima*	Seed	-26.38	10.12	43.97	4.57	11.22
15195	*Cucurbita maxima*	Seed	-26.31	9.01	48.13	5.09	11.03
15196	*Cucurbita maxima*	Seed	-27.61	10.30	48.43	4.28	13.19
15197	*Cucurbita maxima*	Seed	-22.35	15.22	48.69	3.25	17.47
15198	*Cucurbita maxima*	Seed	-23.47	17.05	48.23	3.01	18.69
15199	*Cucurbita maxima*	Seed	-22.33	13.75	47.66	2.95	18.84
15200	*Cucurbita maxima*	Seed	-22.13	13.74	46.34	2.68	20.17
15201	*Cucurbita maxima*	Peduncle	-25.95	15.59	49.15	0.71	80.47
15202	*Cucurbita maxima*	Peduncle	-26.56	15.85	49.05	0.60	95.34
15203	*Cucurbita maxima*	Peduncle	-26.12	11.51	47.53	1.08	51.33
15204	*Cucurbita maxima*	Seed	-25.29	14.94	32.78	3.53	10.83
15205	*Cucurbita maxima*	Seed	-21.65	10.54	47.58	4.01	13.84
15207	*Cucurbita maxima*	Seed	-24.61	8.21	57.32	4.56	14.65
15208	*Cucurbita maxima*	Seed	-26.35	16.85	59.37	5.12	13.53
15209	*Cucurbita maxima*	Seed	-26.49	16.15	55.99	4.39	14.87

15210	*Cucurbita maxima*	Seed	-26.21	17.33	55.99	5.64	11.59
15214	*Cucurbita maxima*	Peduncle	-25.68	12.31	48.84	0.59	96.53
15215	*Cucurbita maxima*	Peduncle	-25.28	15.84	47.27	0.58	95.03
15172	*Cucurbita* sp.	Seed	-23.62	11.75	49.53	3.86	14.96
15173	*Cucurbita* sp.	Seed	-23.20	11.76	45.35	3.31	15.98
15174	*Cucurbita* sp.	Seed	-25.00	11.54	45.03	3.31	15.86
15206	*Cucurbita* sp.	Peduncle	-25.56	13.51	47.24	0.63	87.45
15211	*Cucurbita* sp.	Seed	-23.22	15.07	47.47	4.08	13.57
15212	*Cucurbita* sp.	Peduncle	-25.55	12.35	48.14	0.91	61.70
15213	*Cucurbita* sp.	Peduncle	-25.70	13.17	47.80	1.08	51.62
15220	*Cyperus* sp.	Fiber	-26.37	7.65	42.63	1.93	25.76
15221	*Cyperus* sp.	Fiber	-26.28	6.65	43.85	1.32	38.74
15222	*Cyperus* sp.	Fiber	-26.55	6.12	40.09	1.31	35.69
15223	*Cyperus* sp.	Fiber	-26.35	6.36	37.54	1.51	28.99
15224	*Cyperus* sp.	Fiber	-26.88	7.48	40.47	1.37	34.45
15225	*Cyperus* sp.	Fiber	-26.73	6.00	43.33	1.39	36.35
15226	*Cyperus* sp.	Plaited rope	-26.20	12.32	37.49	1.49	29.34
15227	*Cyperus* sp.	Plaited rope	-25.49	12.75	34.22	1.71	23.34
15228	*Cyperus* sp.	Plaited rope	-26.69	12.92	32.24	1.52	24.74
15229	*Cyperus* sp.	Plaited rope	-25.90	12.93	37.65	1.15	38.18
15230	*Cyperus* sp.	Plaited rope	-25.41	8.10	43.22	2.01	25.08
15231	*Cyperus* sp.	Plaited rope	-25.18	9.15	41.29	2.08	23.15
15232	*Cyperus* sp.	Plaited rope	-25.45	7.81	43.28	2.31	21.85
15233	*Cyperus* sp.	Plaited rope	-25.47	8.34	43.07	1.77	28.38

15234	*Cyperus* sp.	Plaited rope	-25.68	8.64	42.60	1.90	26.15
15235	*Cyperus* sp.	Plaited rope	-26.83	10.64	41.90	1.09	44.94
15236	*Cyperus* sp.	Plaited rope	-25.53	8.93	42.36	1.35	36.59
15237	*Equisetum intectum*	Stem	-21.89	9.62	40.07	0.81	57.69
15238	*Equisetum intectum*	Stem	-23.58	12.71	35.62	0.49	84.78
15239	*Erythroxylum coca*	Seed	-24.79	17.11	48.52	2.62	21.60
15240	*Erythroxylum coca*	Seed	-23.20	14.03	47.02	2.12	25.87
15241	*Furcraea andina*	Fiber	-26.32	11.43	45.39	1.55	34.15
15242	*Gossypium barbadense*	Bract	-22.58	15.90	45.68	1.16	45.92
15243	*Gossypium barbadense*	Bract	-25.27	15.21	46.66	0.78	69.77
15244	*Gossypium barbadense*	Seed	-22.50	14.04	50.74	2.76	21.44
15245	*Gossypium barbadense*	Seed	-22.24	13.74	48.63	2.52	22.51
15246	*Gossypium barbadense*	Fiber	-20.57	14.87	42.83	0.70	71.29
15247	*Gossypium barbadense*	Boll cortex	-19.67	15.23	43.17	0.82	61.69
15248.1	*Gossypium barbadense*	Boll cortex	-21.51	14.69	43.94	1.06	48.33
15248.2	*Gossypium barbadense*	Fiber	-20.28	15.77	42.64	0.51	98.38
15248.3	*Gossypium barbadense*	Seed	-20.21	15.63	45.34	1.63	32.36
15249.1	*Gossypium barbadense*	Boll cortex	-21.96	15.58	44.00	0.82	62.57
15249.2	*Gossypium barbadense*	Fiber	-21.49	16.24	44.39	0.52	99.89
15249.3	*Gossypium barbadense*	Seed	-21.74	15.12	47.16	4.59	11.98
15250	*Gossypium barbadense*	Fiber	-22.28	15.38	35.08	0.47	87.01
15251	*Gossypium barbadense*	Fiber	-22.16	8.44	31.65	0.52	70.97
15252	*Gossypium barbadense*	Fiber	-21.71	12.90	38.59	0.35	128.72
15253	*Gossypium barbadense*	Seed	-22.12	13.01	50.28	2.97	19.74

15254	*Gossypium barbadense*	Seed	-22.49	14.75	52.40	3.83	15.96
15255	*Gossypium barbadense*	Seed	-22.99	11.41	52.51	4.08	15.01
15256	*Gossypium barbadense*	Seed	-21.87	9.11	49.99	4.57	12.76
15257	*Gossypium barbadense*	Seed	-21.51	9.37	51.47	3.79	15.85
15258	*Gossypium barbadense*	Seed	-22.78	11.89	47.97	3.16	17.70
15259	*Gossypium barbadense*	Stem	-24.54	19.50	41.02	0.78	61.36
15260	*Gossypium barbadense*	Bract	-22.60	9.62	47.60	1.60	34.71
15261	*Gossypium barbadense*	Seed	-23.99	10.78	50.56	4.86	12.12
15262	*Gossypium barbadense*	Seed	-24.47	12.15	51.08	4.12	14.46
15263	*Gossypium barbadense*	Seed	-24.74	11.58	49.69	4.47	12.96
15264	*Gossypium barbadense*	Seed	-22.70	13.80	41.46	4.04	11.95
15265	*Gossypium barbadense*	Fiber	-21.43	11.09	33.01	0.51	76.03
15266	*Gossypium barbadense*	Fiber	-24.39	21.54	37.76	0.34	128.05
15267	*Gossypium barbadense*	Boll cortex	-23.28	12.70	43.56	1.29	39.38
15268	*Gynerium sagittatum*	Stem	-25.79	23.08	42.11	0.17	296.04
15269	*Gynerium sagittatum*	Stem	-25.73	15.26	47.04	0.27	201.78
15270	*Gynerium sagittatum*	Stem	-26.02	11.70	47.84	0.48	117.30
15271	*Gynerium sagittatum*	Stem	-25.99	19.38	47.85	0.32	174.99
15272	*Gynerium sagittatum*	Stem	-25.86	1.13	48.19	0.23	242.92
15273	*Gynerium sagittatum*	Stem	-25.90	10.70	48.16	0.45	124.05
15274	*Gynerium sagittatum*	Stem	-24.29	4.73	22.76	0.22	122.95
15275	*Gynerium sagittatum*	Stem	-25.64	13.05	46.90	0.52	104.62
15278	*Inga feuilleei*	Seed	-26.59	4.75	44.86	4.19	12.50
15279	*Inga feuilleei*	Seed	-23.89	5.40	45.14	3.47	15.17

15280	*Inga feuilleei*	Seed	-24.14	4.87	44.83	3.30	15.86
15281	*Inga feuilleei*	Seed	-25.70	4.27	44.27	3.48	14.84
15282	*Inga feuilleei*	Seed	-23.01	5.87	44.30	3.64	14.19
15283	*Inga feuilleei*	Seed	-24.31	5.18	44.58	3.40	15.28
15284	*Inga feuilleei*	Seed	-24.44	2.71	44.34	3.84	13.46
15285	*Inga feuilleei*	Seed	-23.19	5.36	44.75	3.42	15.27
15286	*Inga feuilleei*	Seed	-24.59	4.13	44.69	3.19	16.34
15287	*Inga feuilleei*	Seed	-27.26	4.63	43.34	2.74	18.44
15288	*Inga feuilleei*	Pod	-25.70	4.34	46.66	1.30	41.74
15289	*Inga feuilleei*	Pod	-23.97	7.05	46.30	0.66	81.91
15290	*Inga feuilleei*	Seed	-25.81	4.74	44.57	3.32	15.66
15291	*Inga feuilleei*	Seed	-25.45	3.06	44.56	2.83	18.36
15292	*Inga feuilleei*	Seed	-23.04	0.70	44.90	4.96	10.55
15293	*Inga feuilleei*	Seed	-24.31	1.06	41.08	2.10	22.79
15294	*Inga feuilleei*	Pod	-22.68	1.46	43.70	1.77	28.87
15295	*Inga feuilleei*	Pod	-22.77	3.06	45.09	1.64	32.03
15296	*Inga feuilleei*	Pod	-24.86	11.25	43.48	0.78	64.80
15297	*Inga feuilleei*	Seed	-24.10	0.22	42.77	3.07	16.26
15298	*Inga feuilleei*	Pod	-27.16	1.41	47.25	1.74	31.64
15299	*Inga feuilleei*	Pod	-24.24	9.67	45.55	1.08	49.01
15300	*Inga feuilleei*	Pod	-24.39	5.01	44.19	0.89	57.83
15301	*Inga feuilleei*	Pod	-24.51	4.35	43.30	2.04	24.73
15302	*Inga feuilleei*	Pod	-25.51	13.43	42.46	2.16	22.89
15303	*Inga feuilleei*	Pod	-24.69	0.80	46.62	1.92	28.33

15304	*Ipomoea batatas*	Tuber	-24.91	15.16	41.90	0.75	65.15
15305	*Ipomoea batatas*	Tuber	-25.34	15.84	38.87	0.72	62.95
15306	*Lagenaria siceraria*	Exocarp	-24.61	15.41	48.10	0.60	93.49
15307	*Lagenaria siceraria*	Exocarp	-25.42	13.63	42.52	1.18	42.03
15308	*Lagenaria siceraria*	Exocarp	-23.81	12.87	48.25	0.84	66.99
15309	*Lagenaria siceraria*	Exocarp	-26.77	10.93	46.02	1.28	41.93
15310	*Lagenaria siceraria*	Exocarp	-24.67	14.38	46.78	1.04	52.45
15311	*Lagenaria siceraria*	Exocarp	-23.94	16.34	47.26	0.73	75.50
15312	*Lagenaria siceraria*	Exocarp	-21.68	13.16	47.18	1.10	50.06
15313	*Lagenaria siceraria*	Exocarp	-23.84	13.21	47.18	0.68	80.91
15314	*Lagenaria siceraria*	Seed	-24.09	16.62	50.47	4.40	13.38
15315	*Lagenaria siceraria*	Seed	-24.27	16.99	49.94	4.15	14.04
15316	*Lagenaria siceraria*	Exocarp	-24.90	16.71	48.47	4.23	13.36
15317	*Manihot esculenta*	Stem	-25.79	10.72	39.79	0.83	56.05
15318	*Manihot esculenta*	Stem	-26.86	2.75	40.27	1.39	33.79
15319	*Manihot esculenta*	Tuber	-22.44	6.81	36.33	0.40	105.91
15320	*Persea americana*	Seed	-23.85	13.07	39.28	1.65	27.72
15321	*Persea americana*	Seed	-24.41	15.49	33.18	3.62	10.69
15322	*Persea americana*	Seed	-25.03	11.64	43.05	1.49	33.62
15323	*Persea americana*	Seed	-26.44	12.47	44.07	2.73	18.80
15324	*Persea americana*	Seed	-24.88	8.60	37.06	2.48	17.44
15325	*Phaseolus lunatus*	Seed	-22.55	-1.42	14.4	4.77	3.53
15326	*Phaseolus lunatus*	Seed	-22.64	2.05	39.8	4.1	11.46
15327	*Phaseolus lunatus*	Seed	-23.58	3.71	43.0	4.8	10.52

15328	*Phaseolus lunatus*	Seed	-24.51	2.54	45.2	5.0	10.56
15329	*Phaseolus lunatus*	Seed	-23.34	2.43	42.8	4.8	10.46
15329	*Phaseolus lunatus*	Seed	-23.34	2.21	40.2	4.7	10.01
15330	*Phaseolus lunatus*	Seed	-24.67	2.36	43.7	6.1	8.33
15331	*Phaseolus lunatus*	Seed	-22.73	1.38	43.9	4.4	11.57
15332	*Phaseolus lunatus*	Seed	-22.92	1.29	42.1	4.5	11.00
15333	*Phaseolus lunatus*	Seed	-22.33	1.00	43.9	4.5	11.37
15334	*Phaseolus lunatus*	Seed	-22.94	0.96	37.77	4.84	9.10
15335	*Phaseolus lunatus*	Seed	-23.50	1.76	38.4	4.47	10.03
15336	*Phaseolus lunatus*	Seed	-22.95	1.44	33.0	3.7	10.53
15337	*Phaseolus lunatus*	Seed	-22.90	0.64	44.2	4.25	12.13
15338	*Phaseolus lunatus*	Seed	-23.52	2.49	31.8	4.06	9.12
15339	*Phaseolus lunatus*	Seed	-21.89	2.73	39.6	3.53	13.09
15340	*Phaseolus lunatus*	Seed	-23.33	0.94	24.0	4.43	6.31
15341	*Phaseolus lunatus*	Seed	-23.01	4.05	43.2	4.1	12.35
15342	*Phaseolus lunatus*	Seed	-23.85	1.06	42.6	4.4	11.38
15343	*Phaseolus lunatus*	Seed	-24.98	0.98	22.4	3.82	6.84
15344	*Phaseolus lunatus*	Seed	-23.17	2.02	40.1	4.0	11.56
15345	*Phaseolus lunatus*	Seed	-22.99	4.07	43.5	4.2	12.14
15346	*Phaseolus lunatus*	Seed	-22.40	1.22	44.67	4.83	10.79
15347	*Phaseolus lunatus*	Seed	-22.08	1.09	44.51	3.29	15.78
15348.1	*Phaseolus lunatus*	Seed	-26.95	3.84	43.79	5.46	9.36
15348.2	*Phaseolus lunatus*	Seed	-26.79	3.58	43.47	4.21	12.03
15349	*Phaseolus lunatus*	Seed	-21.90	0.07	41.3	4.5	10.67

15350	*Phaseolus lunatus*	Seed	-22.76	-0.69	41.6	5.1	9.56
15351	*Phaseolus lunatus*	Seed	-22.80	-0.44	44.5	4.9	10.63
15352	*Phaseolus lunatus*	Seed	-22.61	-0.16	43.7	5.2	9.84
15352	*Phaseolus lunatus*	Seed	-22.55	-0.01	45.0	5.0	10.56
15353	*Phaseolus lunatus*	Seed	-23.70	-0.47	40.2	4.1	11.52
15354	*Phaseolus lunatus*	Seed	No reliable data	1.41	44.3	4.0	12.8
15358.1	*Phaseolus lunatus*	Pod	-26.87	3.20	24.8	2.5	11.79
15358.2	*Phaseolus lunatus*	Seed	-26.70	3.69	37.7	4.3	10.18
15359	*Phaseolus lunatus*	Seed	-26.81	0.67	42.72	3.59	13.88
15360	*Phaseolus lunatus*	Seed	-23.38	2.45	40.32	2.23	21.08
15361	*Phaseolus lunatus*	Seed	-25.14	1.42	41.94	4.09	11.96
15362	*Phaseolus lunatus*	Seed	-24.96	1.14	41.54	3.51	13.80
15363	*Phaseolus lunatus*	Seed	-23.04	3.28	42.3	6.6	7.48
15366	*Phaseolus* sp.	Seed	-25.90	2.09	41.16	3.27	14.66
15367	*Phaseolus* sp.	Seed	-25.35	3.14	41.80	3.21	15.19
15368	*Phaseolus* sp.	Seed	-24.49	1.24	42.77	3.25	15.34
15369	*Phaseolus* sp.	Seed	-25.31	1.26	44.20	3.63	14.20
15370	*Phaseolus* sp.	Seed	-24.13	4.20	43.31	4.13	12.23
15371	*Phaseolus* sp.	Seed	-24.53	1.08	42.69	3.44	14.49
15372	*Phaseolus* sp.	Seed	-25.41	2.41	42.08	3.41	14.38
15373	*Phaseolus* sp.	Seed	-25.46	1.58	42.72	3.30	15.11
15374	*Phaseolus* sp.	Seed	-24.75	1.50	43.10	4.59	10.95
15375	*Phaseolus* sp.	Seed	-25.94	0.84	41.71	4.02	12.09

15376	*Phaseolus* sp.	Seed	-22.78	0.54	45.41	4.91	10.78
15377	*Phaseolus* sp.	Seed	-22.14	0.45	45.74	4.64	11.50
15378	*Phaseolus* sp.	Seed	-23.89	2.39	43.41	3.15	16.07
15379	*Phaseolus* sp.	Seed	-25.66	1.32	43.56	4.19	12.12
15380	*Phaseolus* sp.	Seed	-23.39	2.80	45.46	4.21	12.58
15381	*Phaseolus* sp.	Seed	-25.33	1.60	43.04	3.24	15.49
15382	*Phaseolus* sp.	Seed	-24.64	2.60	44.32	4.54	11.37
15383	*Phaseolus* sp.	Seed	-25.00	5.54	44.42	3.13	16.55
15384	*Phaseolus* sp.	Seed	-24.46	2.16	43.37	4.90	10.31
15385	*Phaseolus* sp.	Seed	-24.76	1.58	43.68	2.64	19.29
15386	*Phaseolus* sp.	Seed	-23.15	2.11	45.24	4.28	12.32
15387	*Phaseolus* sp.	Seed	-23.32	5.12	43.99	4.17	12.30
15388	*Phaseolus* sp.	Seed	-23.32	3.84	44.16	4.63	11.12
15389	*Phaseolus* sp.	Seed	-24.78	6.33	42.80	3.88	12.87
15390	*Phaseolus* sp.	Seed	-25.47	5.38	48.06	3.23	17.35
15391	*Phaseolus* sp.	Seed	-24.07	1.85	44.21	3.18	16.21
15392.1	*Phaseolus* sp.	Pod	-25.39	5.24	41.80	0.57	85.52
15392.2	*Phaseolus* sp.	Seed	-25.15	7.07	43.81	3.28	15.57
15393	*Phaseolus* sp.	Seed	-26.81	1.72	42.28	4.36	11.30
15394	*Phaseolus* sp.	Seed	-24.24	5.13	43.77	3.72	13.71
15395	*Phaseolus* sp.	Seed	-22.74	3.98	46.51	6.39	8.49
15399	*Phaseolus* sp.	Pod	-23.66	10.33	47.74	0.47	118.45
15400	*Phaseolus* sp.	Pod	-23.13	0.92	45.33	2.93	18.05
15401	*Phaseolus* sp.	Pod	-21.75	8.13	45.51	0.49	107.87

15402	*Phaseolus* sp.	Pod	-23.07	3.93	46.35	0.47	115.88
15403	*Phaseolus* sp.	Pod	-23.41	-2.07	45.04	1.42	36.99
15404	*Phaseolus* sp.	Pod	-24.23	4.79	42.57	0.30	165.88
15405.1	*Phaseolus* sp.	Pod	-22.36	8.59	44.77	0.59	88.78
15405.2	*Phaseolus* sp.	Pod	-21.43	3.63	47.80	6.18	9.02
15406	*Phaseolus* sp.	Pod	-22.84	8.48	46.90	0.55	99.82
15407	*Phaseolus* sp.	Pod	-22.56	7.21	47.28	0.59	93.45
15408	*Phaseolus* sp.	Pod	-21.30	6.75	45.91	0.51	104.97
15409.1	*Phaseolus* sp.	Pod	-25.50	5.11	47.17	0.77	71.02
15409.2	*Phaseolus* sp.	Seed	-27.02	3.38	59.51	6.64	10.45
15412	*Phaseolus* sp.	Pod	-27.09	2.05	38.67	0.44	102.48
15413	*Phaseolus* sp.	Seed	-25.80	2.53	57.59	6.01	11.18
15418	*Phaseolus* sp.	Seed	-25.55	4.47	42.91	3.84	13.03
15419	*Phaseolus* sp.	Seed	-25.38	2.77	41.27	3.97	12.12
15420	*Phaseolus* sp.	Seed	-26.48	1.95	40.53	1.96	24.15
15421	*Phaseolus* sp.	Seed	-26.18	4.17	40.94	2.58	18.51
15422.1	*Phaseolus* sp.	Pod	-24.10	1.66	45.16	1.18	44.63
15422.2	*Phaseolus* sp.	Seed	-24.21	3.59	52.06	6.22	9.75
15423	*Phaseolus* sp. Sub. *nunas*	Seed	-25.95	3.78	55.82	6.02	10.82
15424	*Phaseolus* sp. Sub. *nunas*	Seed	-25.72	2.97	55.10	4.24	15.15
15425	*Phaseolus* sp. Sub. *nunas*	Seed	-25.67	2.93	55.78	6.08	10.71
15426	*Phaseolus* sp. Sub. *nunas*	Seed	-26.39	1.83	57.49	6.78	9.89
15427	*Phaseolus* sp. Sub. *nunas*	Seed	-25.47	3.80	56.38	6.72	9.79
15428	*Phaseolus* sp. Sub. *nunas*	Seed	-26.49	5.34	53.15	5.23	11.85

15429	*Phaseolus* sp. Sub. *nunas*	Seed	-27.35	4.30	57.40	6.72	9.96
15430	*Phaseolus* sp. Sub. *nunas*	Seed	-24.72	2.58	55.99	6.34	10.30
15431	*Phaseolus* sp. Sub. *nunas*	Seed	-23.29	2.96	55.17	6.16	10.44
15432	*Phaseolus* sp. Sub. *nunas*	Seed	-26.07	3.33	58.75	6.81	10.05
15433	*Phaseolus* sp. Sub. *nunas*	Seed	-27.52	3.13	54.15	5.97	10.58
15434	*Phaseolus* sp. Sub. *nunas*	Seed	-25.53	2.85	56.68	6.44	10.26
15435	*Phaseolus* sp. Sub. *nunas*	Seed	-23.54	4.01	58.29	6.38	10.66
15436	*Phaseolus* sp. Sub. *nunas*	Seed	-23.32	3.25	54.81	6.44	9.93
15437	*Phaseolus* sp. Sub. *nunas*	Seed	-26.20	1.67	56.65	7.12	9.28
15438	*Phaseolus* sp. Sub. *nunas*	Seed	-22.58	2.36	41.23	4.06	11.84
15439	*Phaseolus* sp. Sub. *nunas*	Seed	-25.18	2.39	54.20	6.06	10.44
15440	*Phaseolus* sp. Sub. *nunas*	Seed	-28.13	2.09	40.72	3.24	14.66
15441.1	*Pouteria lucuma*	Seed	-28.67	14.37	48.74	0.58	98.00
15441.2	*Pouteria lucuma*	Seed	-27.32	15.24	45.37	2.96	17.85
15442.1	*Pouteria lucuma*	Seed	-28.62	14.34	44.53	0.45	115.47
15442.2	*Pouteria lucuma*	Seed	-25.28	14.60	45.30	2.41	21.94
15443	*Pouteria lucuma*	Seed	-24.07	10.74	49.11	0.58	98.87
15444.1	*Pouteria lucuma*	Seed	-24.03	13.27	50.07	0.61	95.72
15444.2	*Pouteria lucuma*	Seed	-24.58	7.97	47.29	2.65	20.81
15445	*Pouteria lucuma*	Seed	-25.23	17.65	49.31	0.85	67.50
15446	*Pouteria lucuma*	Leaf	-26.12	1.31	37.56	1.50	29.30
15447.1	*Pouteria lucuma*	Seed	-28.01	18.62	50.18	0.47	124.51
15447.2	*Pouteria lucuma*	Seed	-26.74	12.66	48.36	2.57	21.94
15448	*Pouteria lucuma*	Seed	-25.44	16.03	45.29	0.42	125.76

15449	*Pouteria lucuma*	Seed	-25.85	19.72	48.93	0.60	95.10
15450	*Pouteria lucuma*	Seed	-24.11	23.68	49.65	0.79	72.87
15451	*Pouteria lucuma*	Seed	-26.59	25.52	48.90	0.87	65.45
15452	*Pouteria lucuma*	Leaf	-24.87	2.13	43.72	2.93	17.43
15453	*Pouteria lucuma*	Seed	-25.80	10.85	46.47	0.39	137.90
15454	*Pouteria lucuma*	Seed	-21.53	27.95	46.04	0.43	123.86
15455	*Pouteria lucuma*	Leaf	-26.42	9.03	44.68	4.14	12.60
15456	*Pouteria lucuma*	Seed	-26.92	14.23	49.92	0.56	103.87
15457.1	*Pouteria lucuma*	Seed	-26.08	12.15	48.66	0.71	80.34
15457.2	*Pouteria lucuma*	Seed	-24.35	6.58	45.09	1.79	29.31
15458	*Pouteria lucuma*	Seed	-24.84	18.95	46.37	0.71	76.51
15459	*Pouteria lucuma*	Leaf	-28.21	5.17	46.24	3.79	14.23
15460	*Pouteria lucuma*	Leaf	-26.13	2.34	46.28	4.29	12.59
15461	*Pouteria lucuma*	Leaf	-26.14	3.80	46.99	4.62	11.87
15462	*Pouteria lucuma*	Seed	-24.32	16.33	45.73	0.75	71.11
15463	*Pouteria lucuma*	Seed	-26.07	14.31	50.26	0.80	73.27
15464	*Pouteria lucuma*	Seed	-26.23	10.43	43.65	0.91	56.14
15465	*Pouteria lucuma*	Seed	-26.42	12.27	48.87	0.99	57.84
15466	*Pouteria lucuma*	Seed	-26.06	12.61	44.18	0.96	53.82
15467	*Pouteria lucuma*	Seed	-25.91	18.94	43.81	0.86	59.59
15468	*Pouteria lucuma*	Seed	-25.64	15.60	51.21	0.87	68.64
15469	*Pouteria lucuma*	Seed	-24.79	13.33	48.73	0.96	59.08
15470	*Pouteria lucuma*	Seed	-25.41	17.25	50.08	0.85	68.59
15471	*Pouteria lucuma*	Seed	-24.64	13.77	45.12	0.72	72.93

15472	*Pouteria lucuma*	Leaf	-27.03	2.01	49.20	4.71	12.18
15473	*Pouteria lucuma*	Leaf	-26.16	4.11	44.12	3.65	14.10
15474	*Pouteria lucuma*	Leaf	-25.56	3.78	47.15	4.18	13.14
15475.1	*Pouteria lucuma*	Fruit pulp	-30.06	11.78	31.03	1.64	22.06
15475.2	*Pouteria lucuma*	Fruit rind	-30.22	11.29	38.30	1.77	25.24
15476.1	*Pouteria lucuma*	Seed	-25.84	14.31	43.74	1.12	45.54
15476.2	*Pouteria lucuma*	Seed	-25.52	11.53	44.84	1.65	31.69
15477	*Pouteria lucuma*	Seed	-25.49	13.58	48.80	0.89	63.94
15478.1	*Pouteria lucuma*	Fruit	-25.08	15.63	51.50	2.31	26.00
15478.2	*Pouteria lucuma*	Fruit	-26.17	10.01	52.88	7.10	8.68
15478.3	*Pouteria lucuma*	Fruit pulp	-26.10	17.71	48.15	3.38	16.61
15479	*Pouteria lucuma*	Seed	-28.07	18.28	43.25	0.71	71.04
15480	*Prosopis pallida*	Pod	-23.95	5.11	46.64	1.29	42.28
15481	*Prosopis pallida*	Pod	-26.10	8.78	44.57	2.87	18.11
15482	*Psidium guajava*	Branch	-25.91	19.41	48.69	1.49	38.12
15483	*Psidium guajava*	Branch	-23.65	10.73	37.27	1.07	40.62
15484	*Psidium guajava*	Branch	-26.81	16.37	39.22	0.83	55.18
15485	*Psidium guajava*	Branch	-24.79	12.71	48.76	1.59	35.68
15486	*Psidium guajava*	Branch	-22.49	20.55	47.31	0.68	81.13
15487	*Psidium guajava*	Branch	-24.96	15.41	47.47	1.48	37.41
15488	*Psidium guajava*	Stem	-21.39	11.58	45.24	0.60	87.93
15489.1	*Psidium guajava*	Fruit pulp	-26.17	17.74	43.90	2.31	22.16
15489.2	*Psidium guajava*	Fruit pulp	-25.42	16.51	51.14	0.89	67.00
15490.1	*Psidium guajava*	Fruit pulp	-24.89	11.63	48.26	1.20	46.90

15490.2	*Psidium guajava*	Seed	-25.03	16.63	49.91	1.00	58.20
15491	*Psidium guajava*	Seed	-25.91	9.94	38.26	2.36	18.91
15492	*Psidium guajava*	Seed	-28.50	12.13	42.17	1.92	25.68
15493.1	*Psidium guajava*	Fruit pulp	-24.76	11.23	43.37	1.67	30.25
15493.2	*Psidium guajava*	Seed	-25.39	12.16	44.35	2.18	23.72
15494.1	*Psidium guajava*	Fruit pulp	-22.81	15.21	48.57	0.90	62.94
15494.2	*Psidium guajava*	Seed	-22.97	13.48	48.01	1.36	41.17
15495	*Psidium guajava*	Fruit pulp	-25.11	15.16	48.34	0.97	58.40
15496	*Psidium guajava*	Fruit pulp	-24.64	15.72	46.82	1.30	42.00
15497	*Psidium guajava*	Fruit pulp	-25.06	16.02	48.64	2.19	25.90
15498	*Psidium guajava*	Fruit pulp	-27.07	11.93	44.56	0.86	60.42
15499	*Psidium guajava*	Branch	-22.45	6.58	47.33	0.89	61.83
15500	*Psidium guajava*	Fruit pulp	-22.77	15.18	49.37	1.03	56.15
15501	*Psidium guajava*	Peduncle	-23.43	13.64	45.16	1.33	39.60
15502	*Psidium guajava*	Peduncle	-23.11	14.62	49.28	2.63	21.85
15503	*Salix humboldtiana*	Branch	-23.68	17.89	45.83	0.60	89.01
15504	*Salix humboldtiana*	Capsule	-27.44	9.00	41.31	1.79	26.92
15505	*Salix humboldtiana*	Stem	-26.02	13.59	46.49	0.86	63.05
15506	*Salix humboldtiana*	Stem	-26.30	13.29	44.22	0.82	62.99
15507	*Salix humboldtiana*	Stem	-25.90	9.46	37.71	0.51	85.53
15508	*Sapindus saponaria*	Seed	-24.55	11.09	45.70	1.72	31.03
15509	*Sapindus saponaria*	Seed	-26.07	21.80	48.20	3.76	14.96
15510	*Sapindus saponaria*	Stem	-23.91	17.13	46.46	0.48	112.88
15511	*Schinus molle*	Stem	-25.87	21.27	46.38	0.51	105.71

15512	*Schinus molle*	Stem	-26.19	20.65	45.64	0.25	216.72
15513	*Schinus molle*	Stem	-25.62	0.07	46.37	1.65	32.78
15514	*Schinus molle*	Stem	-23.36	5.86	47.37	0.51	108.33
15515	*Schinus molle*	Stem	-23.88	4.12	49.82	0.52	112.57
15516	*Schinus molle*	Stem	-25.23	6.00	47.91	0.49	112.90
15517	*Schinus molle*	Stem	-24.00	10.40	47.51	0.50	110.93
15518	*Schinus molle*	Stem	-24.15	5.90	45.81	0.66	80.68
15519	*Schinus molle*	Stem	-24.97	6.77	47.23	0.50	110.16
15520	*Schinus molle*	Bark	-26.91	1.54	43.76	1.59	32.04
15521	*Typha angustifolia*	Flower	-25.34	12.35	45.15	1.87	28.20
15522	*Typha angustifolia*	Stem	-28.25	11.15	44.26	0.39	133.68
15523	*Typha angustifolia*	Stem	-28.30	11.53	47.57	0.33	170.01
15524	*Typha angustifolia*	Stem	-25.56	18.16	44.81	0.37	140.24
15525	*Typha angustifolia*	Stem	-26.66	14.13	38.64	0.45	100.14
15526	*Typha angustifolia*	Stem	-26.16	15.31	41.61	0.30	164.33
15527	*Typha angustifolia*	Stem	-27.22	16.07	45.14	0.39	134.90
15528	*Typha angustifolia*	Stem	-26.65	19.74	46.71	0.97	56.42
15529	*Typha angustifolia*	Stem	-26.87	21.14	43.85	1.02	49.92
15530	*Typha angustifolia*	Flower	-25.57	14.82	42.24	1.49	32.95
15531	*Typha angustifolia*	Flower	-25.86	15.83	46.81	3.34	16.33
15533	*Typha angustifolia*	Flower	-24.63	15.20	42.99	1.74	28.75
15216	*Zea mays*	Stem	-10.00	14.24	45.13	0.73	72.10
15217	*Zea mays*	Stem	-10.24	13.37	43.04	0.66	76.04
15218	*Zea mays*	Stem	-9.64	15.01	42.47	0.96	51.59

15219	*Zea mays*	Stem	-10.18	13.81	44.53	0.72	72.12
15276	*Zea mays*	Root	-9.29	18.73	46.13	0.57	94.78
15277	*Zea mays*	Stem	-9.85	15.43	45.69	0.87	61.08
15543	*Zea mays*	Bract	-9.04	3.30	36.33	0.32	134.14
15544	*Zea mays*	Bract	-10.05	3.43	42.07	3.20	15.31
15545	*Zea mays*	Bract	-10.24	-0.83	39.58	0.40	116.15
15547	*Zea mays*	Stem	-10.06	24.93	44.17	2.08	24.72
15548	*Zea mays*	Bract	-10.62	3.42	38.46	0.30	148.60
15550	*Zea mays*	Bract	-10.45	24.09	43.73	0.71	71.61
15554	*Zea mays*	Flower	-8.92	13.34	40.16	0.82	57.17
15555	*Zea mays*	Flower	-9.13	18.01	39.26	0.51	89.11
15557.1	*Zea mays*	Stem	-9.28	12.11	41.38	0.41	118.57
15557.2	*Zea mays*	Root	-8.74	13.53	41.88	0.38	127.98
15571	*Zea mays*	Cob	-10.44	16.09	72.39	1.02	83.10
15587	*Zea mays*	Seed	-9.77	8.99	42.35	1.19	41.53
15603	*Zea mays*	Cob	-10.62	12.26	79.80	1.31	71.23
15604	*Zea mays*	Cob	-10.85	19.23	77.18	1.09	82.69
15605	*Zea mays*	Cob	-11.23	17.02	72.16	1.32	63.61
15606	*Zea mays*	Cob	-10.81	14.46	77.45	1.31	68.73
15607	*Zea mays*	Cob	-11.21	10.41	73.72	1.67	51.63
15608	*Zea mays*	Cob	-10.84	11.95	78.35	1.29	70.82
15609	*Zea mays*	Cob	-10.53	11.97	83.01	1.22	79.11
15610	*Zea mays*	Cob	-10.52	12.82	78.54	1.98	46.32
15611	*Zea mays*	Cob	-10.65	11.31	82.13	1.20	80.13

15612	*Zea mays*	Cob	-10.64	11.42	79.11	1.48	62.20
15624	*Zea mays*	Cob	-9.75	10.47	39.31	0.75	61.20
15625	*Zea mays*	Cob	-10.11	18.74	40.34	0.63	75.06
15626	*Zea mays*	Cob	-10.20	12.19	38.05	1.47	30.23
15627	*Zea mays*	Flower	-9.69	17.89	42.74	0.78	64.31
15628.1	*Zea mays*	Cob	-9.92	15.55	45.05	0.98	53.77
15628.2	*Zea mays*	Grain	-8.35	11.99	37.19	2.34	18.52
15629.1	*Zea mays*	Cob	-9.88	18.13	68.71	1.85	43.29
15629.2	*Zea mays*	Grain	-8.99	19.79	68.61	5.49	14.58
15630.1	*Zea mays*	Cob	-9.61	13.86	45.56	1.69	31.36
15630.2	*Zea mays*	Grain	-9.21	12.60	43.65	3.87	13.17
15630.3	*Zea mays*	Bract	-9.52	13.43	45.04	0.83	63.54
15633	*Zea mays*	Flower	-9.57	8.53	41.30	0.63	76.02
15634.1	*Zea mays*	Cob	-9.57	12.45	43.32	0.63	80.11
15634.2	*Zea mays*	Grain	-9.33	11.78	39.58	1.69	27.29
15635	*Zea mays*	Cob	-9.39	16.02	42.56	0.43	114.29
15636	*Zea mays*	Cob	-9.60	14.06	76.66	3.49	25.59
15637	*Zea mays*	Cob	-8.67	12.66	69.64	5.64	14.40
15638	*Zea mays*	Cob	-10.07	13.51	75.30	2.15	40.92
15639.1	*Zea mays*	Bract	-9.83	17.83	41.65	0.59	82.56
15639.2	*Zea mays*	Grain	-8.80	11.44	41.67	1.24	39.33
15640.1	*Zea mays*	Cob	-9.46	7.68	77.74	2.00	45.40
15640.2	*Zea mays*	Grain	-8.88	11.83	76.71	3.82	23.39
15641	*Zea mays*	Cob	-9.12	8.58	44.18	0.19	272.65

15642	*Zea mays*	Cob	-8.91	8.27	37.54	1.69	25.87
15643	*Zea mays*	Cob	-8.79	8.39	39.53	0.67	69.07
15644	*Zea mays*	Cob	-9.12	13.58	36.88	1.62	26.52
15535	*Zea mays*	Cob	-9.63	22.73	29.5	1.01	34.07
15536	*Zea mays*	Cob	-9.09	19.14	44.0	0.22	234.13
15537	*Zea mays*	Cob	-9.77	12.25	74.17	1.80	47.94
15538	*Zea mays*	Cob	-9.33	16.75	44.5	0.41	127.40
15539	*Zea mays*	Cob	-9.26	12.13	44.1	0.72	71.02
15540	*Zea mays*	Cob	-9.67	9.27	42.1	0.63	77.57
15541	*Zea mays*	Cob	-9.30	16.16	41.4	0.40	121.01
15542.1	*Zea mays*	Cob	-9.43	16.61	45.6	0.75	71.29
15542.2	*Zea mays*	Grain	-8.76	6.80	41.8	2.22	21.96
15542.3	*Zea mays*	Bract	-10.09	12.22	40.2	0.69	68.01
15546	*Zea mays*	Cob	-10.79	12.73	66.88	0.93	83.66
15551	*Zea mays*	Cob	-9.03	8.31	36.44	1.05	40.36
15552	*Zea mays*	Cob	-9.40	16.21	41.7	0.63	76.75
15556.1	*Zea mays*	Cob	-9.93	18.57	38.1	0.45	97.83
15556.2	*Zea mays*	Grain	-8.55	15.09	42.0	1.77	27.68
15558.1	*Zea mays*	Cob	-9.61	13.43	32.2	0.46	81.36
15558.2	*Zea mays*	Grain	-8.99	5.79	37.50	1.25	34.86
15559.1	*Zea mays*	Cob	-9.55	19.32	41.8	0.48	101.56
15559.2	*Zea mays*	Grain	-9.06	7.40	42.0	1.65	29.60
15560.1	*Zea mays*	Cob	-9.64	11.43	39.9	0.46	100.63
15560.2	*Zea mays*	Grain	-9.66	6.28	41.3	1.83	26.27

15561.1	*Zea mays*	Cob	-9.89	12.36	38.09	0.67	66.79
15561.2	*Zea mays*	Grain	-9.35	12.15	39.2	1.72	26.55
15562	*Zea mays*	Grain	-8.80	7.41	36.01	1.22	34.35
15563.1	*Zea mays*	Cob	-9.54	26.16	27.57	0.82	39.19
15563.2	*Zea mays*	Grain	-9.38	7.19	40.76	2.25	21.16
15565	*Zea mays*	Cob	-9.27	6.77	41.50	1.17	41.28
15566	*Zea mays*	Cob	-9.92	5.69	43.72	0.79	64.17
15567	*Zea mays*	Cob	-9.34	17.17	44.87	0.62	84.12
15568	*Zea mays*	Cob	-9.16	33.14	38.44	0.85	52.63
15569	*Zea mays*	Cob	-9.25	10.32	33.83	1.09	36.21
15570	*Zea mays*	Cob	-9.10	13.72	41.11	0.99	48.65
15572	*Zea mays*	Cob	-10.49	14.73	58.25	1.61	42.19
15573	*Zea mays*	Cob	-10.27	16.78	71.05	1.91	43.27
15574	*Zea mays*	Cob	-10.53	15.53	65.30	1.37	55.57
15575	*Zea mays*	Cob	-9.08	17.86	41.29	0.69	69.99
15576	*Zea mays*	Cob	-9.24	12.94	38.28	0.83	53.50
15577	*Zea mays*	Cob	-9.46	9.53	41.74	0.49	99.69
15578	*Zea mays*	Cob	-9.68	8.29	39.94	0.53	87.36
15579	*Zea mays*	Cob	-9.58	10.69	25.84	0.33	90.48
15580	*Zea mays*	Cob	-9.67	16.72	45.82	0.85	62.77
15581	*Zea mays*	Cob	-10.84	17.70	76.52	1.72	51.81
15582	*Zea mays*	Cob	-9.64	14.79	39.15	0.62	73.16
15583	*Zea mays*	Cob	-9.58	18.13	38.71	0.58	78.37
15584	*Zea mays*	Cob	-9.10	18.45	44.68	0.47	110.96

15585	*Zea mays*	Cob	-8.96	23.38	42.69	0.67	74.75
15588	*Zea mays*	Grain	-9.73	7.53	43.19	1.65	30.57
15591	*Zea mays*	Cob	-9.56	10.40	43.31	0.49	102.98
15592	*Zea mays*	Cob	-8.99	9.60	30.68	0.53	66.93
15593	*Zea mays*	Cob	-11.17	10.83	72.92	1.87	45.45
15594	*Zea mays*	Cob	-8.84	5.83	41.73	0.53	91.04
15595	*Zea mays*	Cob	-9.72	21.32	43.91	0.59	87.51
15596	*Zea mays*	Cob	-10.01	9.45	41.96	0.48	101.74
15597	*Zea mays*	Cob	-9.74	20.69	40.9	0.25	193.13
15598	*Zea mays*	Cob	-9.66	10.08	38.71	0.45	100.26
15599	*Zea mays*	Cob	-9.70	12.37	40.89	0.66	71.93
15600.1	*Zea mays*	Cob	-9.78	2.81	42.79	0.61	82.23
15600.2	*Zea mays*	Grain	-9.17	5.77	40.19	2.62	17.88
15601	*Zea mays*	Cob	-9.17	15.01	44.56	1.20	43.19
15602	*Zea mays*	Cob	-9.96	10.46	42.93	0.47	106.11
15616	*Zea mays*	Cob	-9.68	11.97	45.17	0.36	144.59
15617	*Zea mays*	Cob	-9.94	14.43	44.21	0.90	57.44
15618	*Zea mays*	Cob	-9.66	14.40	44.97	0.58	90.57
15619	*Zea mays*	Cob	-10.03	15.09	43.10	0.41	121.36
15620	*Zea mays*	Cob	-9.46	11.48	42.59	0.45	110.54
15621	*Zea mays*	Cob	-10.35	12.10	43.87	1.02	50.24
15622	*Zea mays*	Cob	-10.18	9.48	42.18	0.62	78.89
15623	*Zea mays*	Cob	-10.00	7.59	45.08	0.57	91.49