The Frontier of Islam: An Archaeobotanical Study of Agriculture in the Iberian Peninsula (c.700 – 1500 CE)

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Volume 1 of 2

Text

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ABSTRACT

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This PhD uses new archaeobotanical research and crop stable carbon ($\delta^{13}C$) isotope analysis to investigate medieval agriculture in the Iberian Peninsula (6th-15th centuries). It takes as its central theme an analysis of the long-standing debates surrounding the impact of the Islamic conquests (c.8th century) on agriculture. Were there major innovations after the conquests, or alternatively, was agriculture characterised by longer-term continuity? There is a long tradition of researching this topic in the Iberian Peninsula using documentary and archaeological evidence, yet archaeobotany has had little impact to date.

Archaeobotanical research was undertaken on eight medieval sites in two study areas in the north-east of the peninsula. The first study area examined two Islamic sites (10th-12th centuries) in Teruel, whilst the second examined six sites dating between the early medieval, Islamic and later medieval periods (6th-15th centuries) in the Huecha Valley, Zaragoza. The archaeobotanical results point towards an overall pattern of continuity in the range of crops cultivated, although a general trend towards increasing crop diversity can be identified through time, reflecting broader patterns seen across medieval Europe and the Mediterranean. Stable carbon isotope analysis of 290 single-entity samples (cereals, pulses) provided insights into crop husbandry practices, highlighting the use of rainfed and irrigated areas for cultivation. The results of this PhD are placed within a wider regional and pan-regional context through a synthesis of previous archaeobotanical research undertaken on Roman to later medieval sites in the Iberian Peninsula. Taken together, it is suggested that the Islamic conquests did not lead to a clear and definable break in agriculture, but rather a series of more incremental and gradual changes can be identified through time. The results have wider implications for understanding the longer-term continuity of Mediterranean agriculture.

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DECLARATION

None of the material contained in this thesis has previously been submitted for a degree at the Durham University, or at any other university.

STATEMENT OF COPYRIGHT

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F*or the medieval inhabitants of the Huecha Valley – Muslims, Christians and Jews – who burnt their crops (repeatedly).*

1 The frontier of Islam

The Islamic 'conquests' of the 7th-8th centuries are widely viewed as a watershed moment in the history of Asia, the Middle East and the Mediterranean. The scale of the early Islamic world (c.8th-12th centuries) was vast, spanning from the Indian subcontinent in the east to the Iberian Peninsula in the west. One of the most significant questions surrounding this period is the extent to which it was characterised by major changes in agriculture. Based primarily on documentary evidence, it has long been suggested that the expansion of Islam was accompanied by the diffusion of new cultivars and crops alongside changes in farming practices, especially irrigation (e.g. Lévi-Provençal 1932, 1953; Lautensach 1960; Houston 1964; Imamuddin 1965; Kress 1968; Glick 1970, 1977, 1979; Bolens 1972, 1977, 1978, 1981; Grigg 1974; Watson 1974, 1981, 1983; Arié 1981: 221-232). This has been linked to a sweeping agricultural transformation, or 'revolution', underpinning wider changes in trade, urbanism and demographic growth. Put simply, agriculture in the early Islamic world is thought to have differed significantly from that of medieval Christendom. Yet while this concept of an 'agricultural revolution' has been highly influential, it is also controversial and the degree of continuity versus change is hotly debated (Squatriti 2014a). The central issues here revolve around scale and timing: were there major innovations in agriculture following the Islamic conquests? Or alternatively, was Mediterranean agriculture characterised by longer-term continuity?

In al-Andalus, that is the areas of Spain and Portugal under Islamic rule between the 8th-15th centuries, the question of agricultural change has been researched for decades (Squatriti 2014a). The focus has been on two key transitions: between the late Roman/early medieval to Islamic period (c. early 8th century), and between the Islamic to later medieval (Christian) period from the 11th and 12th centuries onwards. Current understanding of agricultural change in these two periods is largely dependent on evidence from documentary sources which, while constituting an invaluable source of evidence, only forms one part of the wider picture (e.g. Carabaza Bravo et al. 2004; Hernández Bermejo et al. 2012; Albertini 2013). The development of medieval archaeology in Spain and Portugal in the 1970s-1980s did much to redress this imbalance, providing a focus on rural landscapes and irrigation systems in particular (Carvajal 2014). However, what has not developed so strongly is the use of environmental and bio-archaeological research methods to investigate agricultural change more directly. In particular, one important source of data which has had little impact on this field so far is archaeobotanical research (Peña-Chocarro et al. 2019).

1.1 Aims and objectives

This PhD, therefore uses new archaeobotanical data to investigate agriculture in one region of medieval Iberia (6th-15th centuries AD), and its wider relationship to socio-cultural, economic and political change. The aim is to use archaeobotanical evidence to gain insights into patterns of agricultural production and consumption, including the range of crop species cultivated, their potential uses (food versus fodder), crop-processing methods and storage, as well as the use of wild resources. Information from the associated arable weeds is combined with stable carbon isotope ($\delta^{13}C$) analysis of charred crop remains to investigate the nature of crop husbandry practices, especially the use of rain-fed and irrigated areas. The overarching aim is to examine the degree of continuity versus change in agriculture before and after the Islamic conquests, and to do this, debates are examined at local, regional and pan-regional scales in light of this new evidence and then combined with a wider synthesis of published archaeobotanical studies for Roman and medieval Iberia. The key objectives of the thesis are:

1. To evaluate the role of Islam in the transmission and innovation of agriculture and the transformation of agrarian landscapes. What is the evidence for new crops and cultivars? Did innovation take place only in urban centres? What is the relationship between social status, faith and new crops? Are there regional differences imposed by climate and geography?

2. To assess the evidence for an agricultural 'revolution'. Traditional understanding, based largely on documentary sources and archaeological analyses of irrigation systems, points to a sweeping agricultural transformation. However, this idea has been widely challenged, and archaeobotanical research from other areas of the early Islamic world hints that changes in agriculture may have been more protracted and that the uptake of new crops was smaller in scale and spatially variable.

3. To explore changes in farming practices. Irrigation is central to debates around agriculture in the early Islamic world. Was dry-farming replaced by intensive irrigation-based agriculture and an increased importance of arboriculture and vegetable gardens?

4. To apply new and novel methodologies such as stable carbon isotope analysis of plant remains to enable detailed reconstructions of farming practices, particularly irrigation. By integrating evidence from written records, archaeobotany and stable isotopes, a richer comparative understanding of agriculture can be developed.

5. To examine longer-term patterns of change in agriculture between the Roman and later medieval period. Did the Islamic conquests lead to a break in the 'traditional' rhythms of Mediterranean agriculture centred around rainfed cereal cultivation, vineyards, olive groves and small-scale irrigated horticulture? Or instead, should changes in agriculture be placed within a longer-term perspective, with more minor adjustments and modifications in the range of crops and farming practices?

1.2 Study areas

The Iberian Peninsula is an excellent region to undertake this research due to its position at the frontier between Christian Europe and the Islamic world. The central focus here is on two case studies in present day Aragón in Spain (Figure 1.1). The first case study focuses on two Islamic sites in the south in the province of Teruel while the second examines evidence from six sites dating between the early medieval, Islamic and later medieval periods in the Huecha Valley, Zaragoza, and explores a long-term trajectory of change in a single landscape context. There are currently no published medieval archaeobotanical studies in either region (Peña-Chocarro and Pérez-Jordà 2018). This, coupled with the near-absence of information from documentary sources for the Islamic period, has resulted in a very patchy and incomplete understanding of agriculture. In addition, in the case of the Huecha Valley, the Christian 'conquests' in the 12th century redefined the socio-cultural, economic and political organisation of the region, with a shift to a feudal agricultural system. It is thus possible to compare and contrast agriculture *across* the two different regimes.

1.3 Historical and archaeological context: the north-east of Iberia

1.3.1 Before Islam: late Roman and early medieval period (5th-8th centuries)

Throughout the Iberian Peninsula, the late Roman (4th-6th centuries) to early medieval period is generally characterised by the decline of cities and a change in rural landscapes, though it is still poorly understood from an archaeological perspective (Collins 2004: 197-222, 2014:12-13; Wickham 2005; Diarte-Blasco 2018:150-156). The largest and most important city during the Roman period in this region was Caesaraugusta, present-day Zaragoza, although there were other major urban centres across the north-east and these would later form the basis of many cities during the Islamic and later medieval periods (Glick 2005:116-117; Kulikowski 2011). Within the economy and rural landscapes, one of the important changes was the gradual disappearance of Roman villas (Lewit 2003; 2005; Wickham 2005:473-481; Pietro Brogiolo and Chavarría i Arnau 2008; Bolòs 2009). Whilst our understanding of the transition from the Roman to early medieval period remains murky, the overall picture suggests there was the reshaping of landscapes during the 6th-8th centuries, with an increasingly ruralised economy centred around villages, and away from the Roman rural villa economy of estates (Wickham 2005:488-495; Olmo Enciso 2015).

1.3.2 'Conquest' and consolidation of Islamic rule in the Upper March (8th-10th centuries)

Broadly defined, the north-east of the Iberian Peninsula in the Islamic period formed the 'Upper March' of al-Andalus, a region which spanned from around Huesca in the north to Teruel in the south, with Zaragoza in the centre as its capital (Bosch Vilá 1998). The Upper March formed one of three 'frontier' zones between al-Andalus and the Christian states in the north from the 8th-12th centuries; the other frontiers were the 'Middle March' centred around Toledo and the 'Lower March' centred around Mérida (Manzano Moreno 1991; Kennedy 1996). The Upper March also extended along the Mediterranean coast towards Tortosa, though its limits here are poorly defined and this region also encompassed the 'Eastern March' (Torró 2012). Figure 1.2 displays the areas of the Iberian Peninsula under Islamic rule between the c.9th-11th centuries and 15th century.

The Islamic 'conquest' of areas around the Ebro Valley can be dated to c.720, with Zaragoza being captured in 714 (Manzano Moreno 1991). The Iberian Peninsula was situated at the furthest western extreme of the vast Umayyad caliphate; however, the political geography of the *Dar al-Islam* was profoundly reshaped following revolution in 750, leading to the emergence of the 'Abbasid caliphate at Baghdad (Kennedy 1981:31-45). This led to the collapse of the Umayyad caliphate and, as a consequence, al-Andalus became an independent state in 756, ruled by Umayyad emirs who had fled from the 'Abbasids (Kennedy 1996:38-39). The Upper March had been the scene of rebellions in preceding years, though the Umayyads had begun to firmly establish their rule in al-Andalus by the end of the 8th century (Manzano Moreno 1986; Collins 2014:27-28). Despite this, the Umayyad emirate struggled to maintain control over al-Andalus and regional political instability characterised the 8th to early 10th centuries (Collins 2014). Throughout this period the Upper March was effectively a semi-autonomous region of al-Andalus, largely controlled by descendants from local aristocratic families who had converted to Islam (Kennedy 1996:15, 54-55; Sénac 2000:90-91). The most important of these converted families were the Banū Qasī who became one of the dominant political forces in the region (Viguera Molíns 1995:52-56). Whilst the 'conquests' in the early 8th century marked a watershed moment, the following centuries were primarily characterised by continuity, particularly in rural areas outside cities (Wickham 2005:41; Manzano Moreno 2012:25; Collins 2014:10-12).

It is in the 10th century when the most significant political, economic and cultural changes occurred in al-Andalus with the proclamation of the caliphate of Córdoba (Kennedy 1996:82-108;

Fierro 2005; Manzano Moreno 2012; Collins 2014). In this period, al-Andalus became *the* major power in the western Mediterranean, and it is thought that the state accumulated enormous wealth through tax on agriculture, particularly from irrigated areas (e.g. Watson 1983; Barceló 1985; 1996:45; Kennedy 1996:106-107; Fletcher 2006:62-63; El Faïz 2007; Malpica Cuello 2015:90-91; Manzano Moreno 2006, 2018; Martín Civantos 2018). Wickham (2005:41) has highlighted that the success of the caliphate of Córdoba reflects the emergence of a powerful centralised state by the 10th century.

However, by the beginning of the 11th century, the centralised power of the Umayyads had begun to wane, eventually leading to the collapse of the caliphate of Córdoba in 1031 and the breakup of al-Andalus into independently ruled Taifa kingdoms (Wasserstein 1985:55-81; Viguera Molíns 1994). Throughout al-Andalus this created political turmoil, though in the Upper March the period was characterised by a degree of continuity since the region had already been functioning semi-autonomously (Stalls 1995:9; Kennedy 1996:133-134; Catlos 2004:55). The most important and powerful Taifa kingdom was that of Zaragoza which controlled the majority of the Ebro Valley (Viguera Molíns 1994:59-60). By this period Zaragoza was ruled by Arab families, first the Tujībids and later the Banū Hūd (Kennedy 1996:92). Smaller Taifa kingdoms also emerged around the cities of Tortosa and Lleida to the east, though these became subsumed within the Taifa of Zaragoza (Viguera Molíns 1994:59-60; Brufal 2017:61-62). In the upland south of the region there were two small Taifa kingdoms in Alpuente and Albarracín which were controlled by Berbers (Bosch Vilá 1959; Viguera Molíns 1994:81-84). Many Taifa kingdoms grew powerful and this was clearly seen in large cities which are thought to have prospered economically from industry, trade and especially irrigated agriculture (Wasserstein 1985; Brufal 2017). However, at the same time the Taifa kingdoms were unstable and the 11th century is commonly viewed as a turning point in the history of al-Andalus. At this time the Christian states in the north expanded and the so-called 'reconquest[1]' of al-Andalus gained momentum (Catlos 2018:203-204).

1.3.3 The Christian 'conquests' and the later medieval period (11th-15th centuries)

After the Taifa period, the arrival of the Almoravid ruling dynasty (Berbers from Morocco) in the 11th century marked a significant political shift in al-Andalus (Kennedy 1996:161-166). The Almoravids conquered the independently ruled Taifa kingdoms which had existed from the 10th century, ending with the capture of Alpuente, Albarracín and finally Zaragoza in 1110 (Viguera Molíns 1994:127-128). However, the Christian states in the north had already begun to make

[1] An expedient term, 'reconquest' (or *Reconquista*), is widely acknowledged to be problematic from a historiographical perspective. See Fletcher (1987) for further details.

major territorial gains by this period, notably with the capture of Toledo (1085) and later Huesca (1096) (O'Callaghan 2003:23-31). The Almoravids only briefly held Zaragoza before it was captured by Christian forces in 1118 by Alfonso I for the Aragón (Kennedy 1996:180). With the declining power of the Almoravids, a second short-lived Taifa period (1144-1147) emerged (Kennedy 1996:189-195). The appearance of another Berber ruling dynasty, the Almohads, brought some stability to southern areas of al-Andalus, however the Christian states made significant military gains in the 12th century, capturing Tortosa (1148), Lérida (1149), Teruel (1170) and Cuenca (1177) (O'Callaghan 2003). Thus, throughout the 11th and 12th centuries, the Upper March formed a 'frontier' zone between al-Andalus in the south and the expanding Christian states in the north. Ultimately, the balance of power shifted in 1212 after a decisive Christian victory over the Almohads at Las Navas de Tolosa (O'Callaghan 2003:78). Islamic rule in the peninsula would not, however, come to an end until 1492 with the conquest of Granada. As the frontier between al-Andalus and the Christian kingdoms in the north slid erratically further south, this brought with it key changes. Amongst the most important of these was the reorganisation of rural landscapes, with a transition to a feudal economy (Glick 1995).

1.4 Research themes

1.4.1 An Islamic agricultural revolution?

It is now more than 40 years since Watson (1974) published his seminal article *The Arab agricultural revolution and its diffusion, 700–1100*. In this article, and later works, Watson (1981, 1983, 1994, 1995) used documentary evidence to link the spread of Islam with the diffusion of new crops and farming practices. Those crops listed included several key species in world history – Asiatic rice (*Oryza sativa*), sorghum (*Sorghum* sp.), cotton (*Gossypium* sp.), durum wheat (*Triticum durum*) and sugarcane (*Saccharum officinarum*) – alongside other fruits and vegetables - watermelon (*Citrullus lanatus*), citrus fruits (*Citrus* spp.), artichoke (*Cynara cardunculus*), aubergine (*Solanum melongena*), spinach (*Spinacia oleracea*), date palm (*Phoenix dactylifera*). Tropical crops were also listed - banana (*Musa* sp.), coconut (*Cocos nucifera*), mango (*Mangifera indica*) and taro (*Colcasia* sp.). Though he did not explicitly analyse them, Watson also highlighted the diffusion of new cultivars, as well as their associated weeds. Key innovations in farming practices were also outlined, the most important of which was irrigation. It was this which enabled the cultivation of these 'new' crops, opening up the traditionally dry and 'unproductive' summer period and enabling an intensification of production. The agents of this diffusion were thought in many cases to be migrating farmers (see below), though the gardens of rulers and their courts were also key factors. Taken together, these various 'agricultural innovations' were linked together to argue for an agricultural revolution across the early Islamic world. Juxtaposed against this, in later centuries a decline of 'Islamic' agriculture was highlighted following the Christian 'conquests' of al-Andalus, Sicily and the Latin East, resulting in a transition to a 'feudal' economy which was centred around cereals and vineyards.

Watson was not alone in his observations, nor was he the first to suggest such a transformation in agriculture. A large body of earlier research based on documentary sources had already drawn attention to the widespread diffusion of new crops and farming practices with the advent of Islam (e.g. Scott 1904; Lévi-Provençal 1932, 1953; Lautensach 1960; Houston 1964; Imamuddin 1965; Kress 1968; Grigg 1974). Similarly, around the same time as Watson, others were also highlighting the evidence for changes in crops, irrigation and agricultural knowledge (e.g. Arié 1981: 221-232; Glick 1970, 1977, 1979; Bolens 1972, 1977, 1978, 1981). However, the strength of the 'Watson thesis' lay in its succinct and clear articulation of a grand narrative of agricultural change and its wider relationship to processes of urbanisation, demographic growth and trade across the early Islamic world. As a result, this idea of major agricultural transformation in al-Andalus characterised by the diffusion of new crops and cultivars, together with an expansion in irrigation, has been highly influential and has subsequently generated an immense bibliography of research (Squatriti 2014a). The 'Watson thesis' is widely considered as one of the landmark pieces of research for the study of al-Andalus, particularly so after its translation into Spanish (Watson 1998).

It is worthwhile pausing here to note that documentary sources are the principal form of evidence in the 'Watson thesis', and other works. The surviving documentary evidence in al-Andalus is one of the richest sources of agricultural literature for any area of the medieval Islamic world. The most important of these sources are almanacs (agricultural calendars) and the books of Filāḥa (agronomic texts) which were compiled principally between the 10th-14th centuries in Córdoba, Toledo and Seville, although most works date from the 11th and 12th centuries (García Sánchez 1992). Many of these agricultural texts have been translated and/or studied (see below), with several important compilations also being published (e.g. *Ciencias de la Naturaleza en Al-Andalus*; Carabaza Bravo et al. 2004; Hernández Bermejo et al. 2012; Albertini 2013). Nevertheless, it is important to emphasise that there are few surviving sources for earlier centuries (i.e. immediately after the 'conquests'), either in the form of agricultural texts or other works. Similarly, documentary sources pre-dating the Islamic period are almost non-existent, although Isidore of Seville's *Etymologies* (c.615-636) lists a wide range crops and he provides an important point of reference for the introduction of new crops recorded in subsequent Islamic agricultural texts

(Barney et al. 2006). Consequently, when discussing the diffusion of new crops into al-Andalus on the basis of documentary evidence, historians and Arabists are limited to the earliest surviving evidence, as opposed to earliest *actual* reference to a crop.

A key source for studying the diffusion of crops into al-Andalus is the *Kitāb al-anwā'*, or *Calendar of Córdoba*, compiled in 961 for the caliph al-Hakam II; this is the earliest surviving piece of agricultural literature (Pellat 1961). It takes the form of an almanac, a form of calendar, outlining a range of agricultural activities on monthly basis such as irrigation, crop cultivation and harvesting, possibly in relation to the collection of taxes, or as a form of encyclopaedia (Pellat 1961; López López 1994; Christys 2002:121; Trillo San José 2004:47-48). Importantly, it provides the first textual evidence for several new crops: grapefruit or possibly citron, rice, aubergine, sugarcane, cotton, banana, watermelon and a type of cucumber, alongside more typical Mediterranean crops such as cereals, pulses, vines and olives (López López 1994). The extent that the *Calendar of Córdoba* reflects the actual, widespread cultivation of these new crops is unclear (Anderson 2013:114), however, it is widely considered to be the most important and reliable source in tracing the introduction of new crops into al-Andalus and reflects a fundamental change in agriculture by the 10th century (e.g. Watson 1983; Hernández Bermejo 1987; García-Sanchez 1992; López López 1994; Barceló 1996; Hernández Bermejo and García Sánchez 1998; Trillo San José 2004; Ruggles 2006; Hernández Bermejo et al. 2012; Albertini 2013). Later agronomic texts include those by an anonymous author (10th/11th century), Ibn Wāfid (11th century) and Ibn Baṣṣāl (11th/12th century) who provide references to further new crops including spinach, sorghum, bitter orange, pomelo and apricot (Hernández Bermejo et al. 2012).

Aside from this evidence for the introduction of new crops, the agronomic literature underlines a vast breadth of contemporary knowledge about a diverse range of crops, with hundreds of different genera/species and new cultivars being referred to in the 11th and 12th centuries by the agronomists Ibn Baṣṣāl, Ibn Wāfid and Ibn al-'Awwām (García Sánchez 1992). These sources detail aspects such as soil, irrigation, viticulture, arboriculture, horticulture and arable cultivation alongside processing, storage and different uses of crops. Particular emphasis is placed on irrigated agriculture, specifically horticulture (fruit trees, vines and vegetables are covered in detail), highlighting the importance of these crops. Cereals are also covered in detail, although they receive less attention than (irrigated) arboriculture or horticulture. However, the 12th century agronomist Al-Ṭighnarī regarded cereals as forming the basis of diets, and Hernández Bermejo et al. (2012:184) noted agronomic texts may have paid less to attention to cereals since agronomists were already very familiar with their cultivation compared to new or more unusual crops.

In many cases, these agronomic texts appear to have had didactic purpose. For example, Abū ’l-Khayr (11th century) goes into great detail on the propagation and cultivation of olives, whilst Ibn al-‘Awwām (12th century) in describing barley provides meticulous detail on the types of seedcorn, the best soils to sow on, the number of times a field should be ploughed, rotation with wheat, methods of sowing, harvesting dates, threshing and the uses of the crop (Ruggles 2006: 22-29; Hernández Bermejo et al. 2012:127-222). The purpose of these texts is debated as they are in one sense working manuals, yet at the same time it is important to emphasise their context of production in royal and courtly circles in Córdoba, Toledo, Seville and Almería (Retamero 1998; Anderson 2013:113). How far they reflect the reality of agriculture in rural areas is unclear; their perspective is skewed towards irrigated botanical gardens, palace gardens and agricultural estates, as well (sub-)urban irrigated areas, or *huertas* (Horden and Purcell 2000:259-260; Anderson 2013:113-118).

Nevertheless, this agronomic literature undoubtedly reflects an upsurge in knowledge which built upon earlier classical foundations and which was greatly expanded through first-hand experimentation (Bolens 1981; Butzer 1994; El Faïz 2005, 2007; Albertini 2013). In some cases, agronomists such as Ibn Baṣṣāl had obtained knowledge on the cultivation of crops during their travels across the Mediterranean. Some consider this expansion of ‘Islamic’ agronomy between the 10th-12th centuries to be the defining element of al-Andalus (e.g. Bolens 1981; Samsó 2011: 277-305; Albertini 2013). Certainly, the impressive breadth of knowledge on a diverse range of crops and other plants is also reflected in contemporary medical and pharmaceutical texts (Llavero 1990). The development of botanical gardens and palace gardens was an important feature of this period as new plant species were introduced and acclimatised in gardens and agricultural estates; these were also opportunities for experimentation (Hernández Bermejo 1987; Ruggles 2006; García Sánchez 2011; Anderson 2013).

A well-known early example of these processes of plant translocation is provided by the diffusion from Damascus of a new variety of pomegranate, the safarī, in the 8th century to the royal court in Córdoba (Martínez Enamorado 2003:114-116). Seeds/cuttings were subsequently propagated on an agricultural estate near Málaga and from there diffused throughout al-Andalus. Martínez Enamorado (2003:116-117) also draws attention to the introduction and acclimatisation of banana and sugarcane in the 10th century in Málaga. A similar pattern of plant translocation is provided by the diffusion of a new fig, the *doñegal*, which was illicitly smuggled from

Constantinople to Córdoba where it was passed to the emir, probably Abd al-Rahman II (Fletcher 2006:62). Stories of plant translocations such as these are likely to be in part apocryphal, although they do reflect the reality of plant translocations (Glick 2005:70-71). Many of these botanical gardens, palace gardens and agricultural estates are known to have existed across al-Andalus from the 8th century, particularly in the south (Ruggles 2006). However, it is important to emphasise that primary agents in this diffusion of crops and irrigation are thought to have been peasants themselves (Glick 1970, 2005; Watson 1983, 1995; Barceló 1995, 1996; Glick and Kirchner 2000; Kirchner 2009; Retamero 2009; Martín Civantos 2011; Kirchner and Retamero 2015).

An indication of changes in agriculture across al-Andalus is also provided in an earlier geographical work by al-Rāzī in the 10th century (Trillo San José 2004). In particular, al-Rāzī provides abundant references to different areas of al-Andalus, especially cities, remarking on the abundance of cereal fields, irrigated *huertas* and *vegas* (sub-urban cultivated areas), lavishing with praise the quality of many different kinds of agricultural produce; fruits being a particular source of fascination. For example, references are provided to the cultivation of 'every kind of fruit tree' in in Córdoba, whilst Málaga is abundant in vines and fruit trees, Valencia is remarked upon for the quality of its saffron, and Zaragoza is known for the high quality of its soil and abundant irrigated areas with fruit trees. Later geographical works by al-Zuhrī (11th century), al-Idrīsī (12th century) and al-Himyari (14th century) all echo similar views; giving the impression that al-Andalus abounded in irrigated areas, with rich and diverse agricultural produce. On the one hand, descriptions of irrigated areas, fruit trees and gardens are also reflected in contemporary poetry and resemble the Paradise Garden in the Koran (Glick 2005:45-46) and should perhaps not be taken too literally. Despite this, rare evidence from *hisbas* (rules governing the sale produce in markets) and cookbooks (dating from the 13th century) do nonetheless hint at the richness and diversity of agricultural produce in urban areas (e.g. García Gómez 1957; Vallvé 1983; Waines 1992; Zaouali 2009). In fact, Constable (2013) draws attention to the social dimension of changes in agriculture, with changes in crops having a wider link with faith, ethnicity and status. Some food and foodways came to be distinctive markers of Muslim identity such as the consumption of figs, raisins and couscous, alongside eating whilst seated on the floor. The impression given by the documentary sources is not just of an agricultural intensification or expansion, but one which affected the rhythms and routines of daily life.

Closely related to this intensification of agriculture is the increasing commercialisation of agricultural products. For example, this is seen in the exportation of olive oil which according to al-Idrīsī (12th century) was produced on a vast scale in Seville, although other areas of al-Andalus such as Lleida in the north were also known for the production of olive oil (Glick 2005:73-74). Dried fruits were also an important export, especially figs, which were exported across the Mediterranean from southern and eastern areas of al-Andalus. In particular, dried figs from Málaga were amongst the most highly prized. There are several indications of a major increase in fig cultivation in al-Andalus, and Glick (2005:74) notes that the Arabic term for 'fig' became a synonym for 'tree', emphasising their widespread cultivation. Raisins were another important dried fruit produced from irrigated areas. Evidence for the increasing commercialisation of the agricultural economy can also be seen in the cultivation of textile plants including flax, hemp, cotton and silk (produced on the mulberry tree), alongside dye plants such as henna (*Lawsonia inermis*) and saffron (*Saffron crocus*) (Lagardère 1990, 1993; García Sánchez 2001; Contable 1994). Thus, for example, al-Istajn in the 10th century admired the high quality of silk production in al-Andalus, and Ibn Ibn-Ḥawqal, a geographer who visited al-Andalus in the 10th century, remarked on the quality of linen and silk production (Trillo San José 1999). The Cairo Geniza documents, Jewish manuscripts documenting trade across the Mediterranean, highlight the importance of textile exports from al-Andalus, especially silk (Goitein 1961; Constable 1996:173-181).

Paradoxically, despite the abundance of agronomic literature, a key source of evidence absent in al-Andalus is typical archival documents such as land registers, agricultural tithes, sales of land etc. (Guichard and Lagardère 1990; Guichard 1999). In later medieval Iberia (i.e. post-conquest), as elsewhere in medieval Europe, documents such as these can provide invaluable information about agriculture (Kirchner 2019). Thus, for instance in the north-east of Iberia, only a handful of sources for the Islamic period provide fleeting and scant information on irrigated areas and the crops cultivated, focusing almost solely on urban areas (Ortega Ortega 2010:127). In the south of the peninsula the situation is different and a richer body of documentary source is available since these areas were conquered at a later date (13th-15th centuries), although we still lack early sources (e.g. Trillo San José 1999, 2004; Domínguez Rojas 2006). Consequently, a big part of the picture is missing for al-Andalus, especially in rural areas. In many cases, one of the principal sources for understanding the crops cultivated in specific areas across al-Andalus is provided by documentary sources generated after the Christian 'conquests' (e.g. Kirchner et al. 2014). However, such sources often only provide generic references to the crops which were cultivated (i.e. 'cereals', 'figs', 'fruit trees'). In a rare case from Mallorca, one post-conquest document relating to a rural *alquería* (hamlet/farmstead) recorded mulberry trees, broad beans, peas, onions, garlic, cabbages, asparagus, plum trees, pomegranate trees, ?bottle gourds, cucumbers, apricot trees, apple trees and citrus fruits, together with other references to barley and wheat (Kirchner 2018:207). Sources such as this allude to the potential range of crops cultivated elsewhere, yet for which no documentary currently evidence exists.

Overall, the pattern which emerges from the documentary sources is one of a sweeping agricultural transformation, with irrigated agriculture being of key importance. These sources give the impression of relatively complete understanding of agriculture, yet on closer examination it is evident that there are clear gaps in the documentary records. In particular, these sources are biased in their chronological and geographical survival, and relevance to actual practice. How can archaeobotany contribute to this topic? In the first instance, archaeobotany provides a direct insight into daily lives, especially that of farmers in what was fundamentally a rural world. Secondly, it provides greater detail and scientific specificity to some areas of agriculture. Documentary sources often only provide generic references to crops such 'cereals', yet the distinction between durum wheat and rye for example is of critical importance to the farmer. Similarly, these sources are also biased to urban areas and they can obscure the rural picture, just as the interests of the wealthy are better represented. That said, the archaeobotanical record too has its challenges. Ultimately, only by interweaving evidence from documentary sources and archaeobotanical research is it possible to develop a more nuanced understanding of agriculture in medieval Iberia.

1.4.2 Irrigated agriculture

The 'centrality of irrigation' to Islamic agriculture, as Glick and Kirchner (2000:276) note, is reinforced by a large-body of archaeological research which has focused on the development, design and organisation of irrigation systems in al-Andalus. In particular, research in eastern areas of al-Andalus and the Balearic Islands has drawn attention to a major expansion in irrigation systems following the Islamic 'conquests' (for a review see Kirchner 2009, 2011, 2019), and this has been linked to the migration of Arabs and Berbers. In turn, the diffusion of new crops listed by Watson (1983) has been understood as part of this migration. An important aspect of this research on the development of irrigated spaces has been the emphasis on the non-feudal nature of agriculture in al-Andalus (Martín Civantos 2011). Instead, the mode of production centred on a tax-based system with the *alquería* (hamlet/farmstead) as the basic fiscal unit, rather than a 'feudal' land, or rent-based system characteristic of later periods. Whilst it is clear from the documentary evidence and archaeological research, there was undoubtedly an expansion and intensification in irrigation following the Islamic 'conquests'. The diffusionist paradigm outlined above which links irrigation systems and the migration of Arabs and Berbers has not gone without criticism. Manzano Moreno (2018), however, questions the archaeological and documentary evidence to support this. In addition, one of the major issues is the difficulty of dating irrigation systems, something that needs to be questioned. The *qanat* (a subterranean irrigation channel) offers an example of the challenges in dating evidence. It is widely assumed that the *qanat* was either a new Islamic introduction, or at least one which became more widely diffused following the Islamic 'conquests' (Gerrard and Gutiérrez 2018a). However, recent OSL dating has identified *qanats* dating to the Roman, later medieval and post-medieval periods in different areas of Spain, with none (at present) directly dated to the Islamic period (Bailiff et al. 2019). We know very little about the scale and development of Roman irrigation, and similarly whether such systems persisted extant and in use into the early medieval period.

In assessing the impact and legacy of the Islamic 'conquests' on agriculture, an important question is to understand changes to agriculture caused by the Christian 'conquests', especially from the 12th century onwards. Watson (1983:184) regarded the Christian 'reconquests' as leading to a decline of 'Islamic' agriculture, with a shift away from polyculture to a less-varied 'feudal' economy with vineyards and, in particular, cereal cultivation taking centre place. This reorganisation of the agricultural economy is to some extent reflected in the copious documentary records for the later medieval period, which do place increasing emphasis on cereal cultivation, as well as the re-organisation of irrigation systems. However, as Butzer et al. (1985) were quick to point out, Watson was mistaken in stating that the 'conquests' led to the supposed 'retreat' of Islamic agriculture. Some crops thought to have newly introduced in the Islamic period, such rice and sugarcane, are known to have been widely cultivated.

1.4.3 Migration and conversion to Islam

It is well-established that large numbers of Arabs and Berbers migrated to al-Andalus in the 8th century; however, there is considerable uncertainty over the full extent of migration with estimates ranging from thousands to tens of thousands (Catlos 2004; Collins 2014:6-10). Evidence for these migrations has primarily been identified from documentary and toponymic evidence (e.g. Guichard 1976), though recent archaeological research has also identified individuals of North African descent in other areas (e.g. Prevedorou et al. 2010; Gleize et al. 2017; Olalde et al. 2019). In the Upper March, the focus of Arab settlement appears to have been in Zaragoza and surrounding areas (Manzano Moreno 1991; Acién Almansa 1999; Ṭāha 1989:115-150). In comparison, there is particularly strong evidence for Berber settlements in the upland south of the region along the Jiloca and Jalón valleys (Bosch Vilá 1959; Ṭāha 1989:173-174; Manzano Moreno 1991; Catlos 2004:25-27; Olmo Enciso 2011; Sarr 2013). However, to some extent both

Arab and Berber settlements appear to have been interspersed throughout the Upper March (Ṭāha 1989).

The migration of Arabs and, in particular, Berbers is widely thought to have had a profound impact on rural landscapes through the introduction and diffusion of new crops, irrigation practices, technological knowledge and changes in the organisation of agricultural spaces. These ideas were laid out in influential publications which have become widely cited by Glick (1970, 1979, 1995), Guichard (1976), Bolens (1981), Watson (1974, 1983, 1995), Bazzana and Guichard (1981), Bazzana et al. (1988) and Barceló (1989, 1995). Consequently, migration has formed a key aspect of debates surrounding the Islamic 'agricultural revolution' and it has generated an immense bibliography. However, it is also a subject which has come under increasing scrutiny in recent years, particularly by Manzano Moreno (2018) and this is outlined in more detail below ('Urbanisation and rural landscapes').

Though migration was an important feature of this period, the majority of the population within the Upper March comprised pre-existing communities which converted to Islam in the centuries following the 'conquest' (Catlos 2004:25). This is reflected in political power of locally-based converted families in this period (Kennedy 1996:15; Collins 2014:41-42). It is, however, important to emphasise that small Christian communities (referred to as *mozárabes*) were still present throughout the Upper March, whilst there were large Jewish communities in some areas such as Zaragoza (Sénac 2000:123-127; Catlos 2004:29-32). These religious minorities co-existed alongside Muslim populations, maintaining a degree of autonomy (Glick 2005:184-186). Despite this, it is thought that the vast majority of the population had converted to Islam by the 11th century, though there is some uncertainty over the timing of this (Catlos 2004:27-28; Glick 2005: 22-24, 210-216). Archaeologically, one of the most visible symbols of this process was the construction of major mosques in large cities such as Zaragoza (Hernández Vera 2004) or Tudela (Cámara and Aranz 1994), alongside smaller mosques which were widely distributed throughout rural areas (Calva Capilla 2011). The proclamation of the caliphate of Córdoba also reflects this process of conversion, with caliphs serving as both political *and* religious rulers (Fierro 2005). This religious transformation, or Islamicisation, should be considered as part of a broader transformation, affecting the daily lives of both Muslims and non-Muslims (Insoll 1999; Carvajal 2014; Gutiérrez Lloret 2015; Thomas et al. 2017).

1.4.4 Urbanisation and rural landscapes

Urbanisation has often been viewed as a defining feature of al-Andalus, and the wider early Islamic world, with cities occupying an intermediary position politically, culturally and economically between the state and rural landscapes (Navarro Palazón and Jiménez Castillo 2007; Acién Almansa 2008; Malpica Cuello 2015; Kennedy 2018). There were several major cities in the Upper March including Zaragoza, Barbastro, Huesca, Tudela, Calatayud, Lleida and Tortosa, as well as many minor ones (Bosch Vilá 1998:381; Kennedy 1996:56). The largest of these was Zaragoza which was one of the most important cities in al-Andalus (Catlos 2018:78). Whilst many of these cities had already developed into large urban centres by the Late Roman period (Magallón Botaya 2006), there is also evidence for the development of new cities such as Calatuyud (Souto 2006). Generally, settlement patterns in southern areas of the Upper March were more dispersed and there were no major cities, though minor urban centres such as Albarracín grew in importance (Bosch Vilá 1959; Navarro Espinach 1999).

In the 10th-11th centuries, and particularly during the Taifa period, cities throughout the Upper March expanded significantly (Brufal 2017). This extended into surrounding sub-urban areas and large irrigated belts (*huertas*) developed around cities such as Zaragoza (Ortega Ortega 2010), Tortosa (Kirchner and Virgili 2019) and Tudela (Hernández Charro 2007) amongst others. Whilst dating the origin of these urban *huertas* remains problematic, the development of these intensively cultivated areas throughout al-Andalus has been closely linked to debates surrounding the introduction of new crops and the commercialisation of agriculture with an expansion in 'cash-crops' such as flax, dried fruits and possibly perishable vegetables such as spinach and aubergine (Glick 1970:197; Watson 1983, 1995:67; Barceló 1989; cf. Martín Civantos 2018; Gutiérrez Lloret 2019; Kirchner 2019).

Although there were major cities in al-Andalus, it is important to emphasise that the population was primarily rural (Catlos 2004:33; Eiroa Rodríguez 2012). Therefore, understanding the nature of rural settlements, and their relationship to agriculture, is a key research area. It has long been suggested that the near-universal form of rural settlement throughout al-Andalus comprised a fortified refuge (*hisn* sing./*husun* pl.) which was surrounded by a network of c.10 small hamlets/farmsteads (*alquería* sing./*alquerías* pl.); this is commonly referred to as the *hisn/qarya* complex (Bazzana and Cressier 1981; Bazzana et al. 1988; Glick 1995:13-29). *Husun* were generally situated on areas of elevated ground and have a relatively standardised layout comprising a fortified tower surrounded by a large walled enclosure, water cisterns and *silos*/storage pits (Sénac 1998). In comparison, *alquerías* were dispersed across areas of low-ground and invariably constructed around small irrigated areas (Glick 1995:84-87; Barceló 1989, 1995). A key feature of the *hisn/qarya* complex is the link between these settlements and the migration of Arabs and especially Berbers. It has been suggested that these ethnic groups maintained their own forms of tribal/clan structures intact following the colonisation of rural areas (Guichard 1976; Bazzana et al. 1988; Barceló 1985, 1989; Glick 1995:51-60).

This generalised model, first developed for southern and eastern areas of al-Andalus, has remained at the core of debates surrounding rural settlements in al-Andalus since the 1980s, though it is widely recognised that it needs to be revised by new archaeological research (Manzano Moreno 2006, 2012, 2018; Eiroa Rodríguez 2012; Molinari 2015). For instance, as further archaeological research has been undertaken it has become apparent that the *hisin/qarya* complex does not reflect a pattern of uniform settlement in all areas (Manzano Moreno 2006:433-437). One aspect which has been significantly revised and downplayed in recent years is the importance of tribal/clan structures in the organisation of agricultural landscapes (Manzano Moreno 1993, 2006, 2012, 2018; Catlos 2004:39-44; Boone 2009:95-127; Malpica Cuello 2015; Ortega Ortega 2018: 255-259). Whilst there is ongoing debate over how agricultural landscapes were organised at local levels and how this related to the state, it is generally accepted that al-Andalus was not a feudal society (Molinari 2015). In essence, it is argued that a 'tax-based' system existed in al-Andalus which was centrally controlled by the state; *alquerías* formed the basic fiscal unit and these were managed by the rural community (Barceló 1985). This can be contrasted against the feudal 'land-based' or 'rent-based' system centred around seigneurial lords which was typical of later medieval/Christian society in the Iberian Peninsula (Glick 2005; cf. Wickham 1984, 2005:58).

In contrast to other areas of al-Andalus, there has been little in-depth archaeological research into the nature of rural settlement patterns in the Upper March (Eiroa Rodríguez 2012; Caetano Leitão 2018) and very few documentary sources exist for this period (Souto 1992). The available Islamic sources (9^{th}-10^{th} centuries) provide only a partial picture of rural landscapes, with incidental references to *husun*, *alquerías* and irrigation for some areas along the Ebro and its associated tributaries (Souto 1992; Ortega Ortega 2010). In comparison, a large body of documentary evidence exists for the period immediately following the Christian 'conquests' in the late 11^{th}-12^{th} centuries (Catlos 2002; Laliena Corbera 2010:40). In areas along the central Ebro Depression, these sources contain abundant references to *almunias*; sites which are thought to have been privately-owned farmsteads/estates linked to urban elites. However, the term *almunia* appears to reflect a wide variety of settlement types and the distinction between *almunias* and *alquerías* is far from clear cut (Sénac 2000, 2012; Ortega Ortega 2010:129-132; Laliena Corbera 2010; Brufal 2017). Currently, the only areas where rural settlements have been investigated in detail through survey and excavation are to the north of the Ebro River (Sénac 2012) and consequently it is difficult to provide any conclusions concerning the nature of rural settlement patterns more widely (Catlos 2002).

The highest densities of rural settlements are typically found along the Ebro and its associated tributaries, though few distribution maps of settlement patterns exist at present (Sénac 1998; Brufal 2011; Laliena Corbera 2010:41-42). Documentary sources and archaeological data suggest that many of these areas along the Ebro River and associated tributaries such as the Jalón (Ortega Ortega 2010) and Huecha (Teixera 1995) were irrigated. The full extent of these irrigation systems in the Islamic period is difficult to quantify and a key challenge is establishing dating evidence for the irrigated areas. Beyond these valleys, areas predominantly associated with dry-farming also appear to have been widely settled (e.g. Brufal 2011), although this tends to be overlooked in research and they are still poorly understood (Jiménez Castillo and Simón García 2018). At a broad level, *husun* can be identified throughout the Upper March and north of the Ebro detailed research suggests that they were a key component in the organisation of rural landscapes, perhaps as points of contact between the state and rural populations (Sénac 2012). However, this does not reflect a uniform pattern and *husun* appear absent in southern areas of the Upper March around the Iberian System, where research has instead identified evidence for groups of *alquerías* and occasional small fortified towers (*burjs*) (Ortega Ortega 1998; Laliena Corbera 2007:142-144). Overall, throughout the Upper March, rural settlements could vary widely in size from large sites such as Las Sillas (Huesca) with a population of c.200, a mosque and large courtyard houses, to more dispersed settlements (Sénac 2008; Laliena Corbera 2010). It is thought there was a significant population expansion in rural areas in the 10th century (Laliena Corbera 2010:39).

1.5 Organisation of thesis

Chapter 2 presents the archaeobotanical methodology for the samples studied in this thesis, focusing on site selection, and the sampling and analysis of the data. Following this, the methods used to identify crop husbandry practices - arable weeds and stable carbon isotope analysis - are outlined. In both cases, an overview is provided of the methodological principles underlying each form of analysis.

Chapters 3 and 4 present the archaeobotanical and crop isotope evidence from the two case studies. In each area, a summary of background information on the history, archaeology and geography of the sites contextualises the evidence. The archaeobotanical and crop isotope evidence is examined for each site individually and the results are discussed within a local context, drawing on information from documentary (where available) and archaeological evidence.

Chapter 5 takes the archaeobotanical evidence outlined in Chapters 3 and 4 and places it within a regional context focusing on the north-east of Spain, exploring evidence from the whole of Iberia. Chapter 6 provides a conclusion to the thesis, reflecting back on the aims and objectives presented in Chapter 1, in particular the long-standing debates surrounding the impact of the Islamic ‘conquests’ on agriculture.

2 Methodology

The first section of this chapter presents the archaeobotanical data collection methodology, focusing on the sites sampled, sampling strategies, laboratory methods and dating evidence. The second and third sections present the methodologies used to identify crop husbandry practices, highlighting the contributions of weed assemblages and stable carbon crop isotope analysis. The methodological frameworks underpinning the analysis of weed assemblages and crop isotope evidence are provided.

2.1 Archaeobotanical Data Collection

2.1.1 Sites and data collection

Archaeobotanical data was primarily collected from sites which were excavated during the earlier stages of this PhD research (2016-2018). A small number of samples taken during previous excavations (i.e. before 2016) have also been included (see below). Summary information for the sites sampled in the two study areas is provided in Tables 2.1 and 2.2. Detailed contextual information for the samples is provided in Chapters 3 and 4, in conjunction with the archaeobotanical evidence.

In the Teruel case-study area, archaeobotanical data was collected from Islamic sites through collaboration with the research project *Husun y Qura: Estudio del poblamiento andalusí* (Villagordo Ros 2018). In the Huecha Valley case-study area, new fieldwork was undertaken as part of this PhD and this produced the majority of the archaeobotanical dataset for this study area. This comprised a series of small-scale excavations at Bureta, La Mora Encantada and Palacio de Bulbuente. To supplement the dataset, a modest number of samples taken during previous excavations were also included from Iglesia de San Miguel de Ambel, Casa Conventual de Ambel and Castillo de Grisel. Since very few medieval sites have been excavated, and none have been comprehensively sampled for archaeobotanical remains, new fieldwork was an essential component of this PhD research. This fieldwork was associated with a wider research project within the study area, the *Moncayo Archaeological Survey* (Gerrard and Gutiérrez 2012, 2020).

Bulk soil sampling to collect archaeobotanical data is typically not undertaken on excavations on medieval sites in Spain and there was little/or no 'pre-existing' dataset which could be analysed. Consequently, to collect the archaeobotanical data it was necessary to excavate new sites and to collaborate with other projects examining Islamic sites. These sites were specifically selected based on their date and location. In all cases, the author was directly involved in multiple excavations and on-site throughout to undertake the sampling or to oversee it (Figure 2.1).

2.1.2 Sampling and recovery

A comprehensive sampling strategy was adopted with samples collected from contexts determined to have high contextual integrity. This judgemental sampling strategy (Jones 1991) was adopted to prioritise contexts with good potential for the recovery of archaeobotanical data and to minimise sampling contexts with poor contextual integrity (i.e. containing mixed material of uncertain date/origin). In most cases, the samples originate from a wide range of primary and secondary deposits (cf. Miksicek 1987; van der Veen 2007; Fuller et al. 2014). This includes silo/pit fills, hearths, floors, occupation layers, refuse/midden-type deposits and conflagration deposits.

The on-site aim was to collect a minimum of 40-60 litres (L) per context (equivalent to 4-6 buckets), or 100% of smaller contexts. Where possible, samples were scanned to assess the quantity of plant remains present and to determine whether the whole sample was processed or whether further, larger samples (>60L) were taken. Previous research suggests that a minimum of 40L per context is necessary to account for potentially low densities of plant remains, particularly within rural sites (e.g. Hoppé 1999; Samuel 2001; van der Veen et al. 2007, 2013; Charles et al. 2009). An exception to this sampling strategy is Ambel Church, excavated in 2007, where small samples (<5L) were taken at the time of excavation from a limited number of contexts (Blanco Morte 2007). In total, 156 samples were analysed for the whole PhD, corresponding to 3585 litres, with sample volumes ranging from <1L to 200L per context (average 32L).

The bulk samples were manually floated with the flots collected on a 300µm mesh, or a 500µm mesh for samples which were difficult to process. Residues were washed through a 500µm or 1mm mesh. Sample processing was primarily undertaken by the author during excavations in Spain with additional sample processing undertaken in the Department of Archaeology, Durham University.

2.1.3 Sorting

Residues were sieved into fractions (>4mm, 2mm, 1mm) and scanned for additional plant remains (e.g. nutshell/fruitstone fragments, pulses, mineralised remains). The >4mm fraction was 100% scanned and, at a minimum, a sub-sample of the 2mm (≥25%) and 1mm (≥12.5%) fractions was scanned under a low-powered microscope. For most samples, 100% of the 2mm fraction was scanned. Where plant remains were present within a residue, it was either 100% sorted or re-floated. To minimise potential damage to plant remains caused by re-wetting/drying, only a small number of samples were re-floated.

Flots were examined at X7.5 to X60 magnification using a Leica M80 stereomicroscope. With the exception of two very large flots from El Quemao (see Chapter 2, section 2.2.2), the coarse fractions (≥1mm) for all the samples were 100% sorted. Sub-sampling (≥12.5%) of the fine fractions (300/500µm) was undertaken for very large and/or rich flots using a riffle box (van der Veen and Fieller 1982). Very large flots were sub-sampled when full sorting of the fine fractions was unlikely to produce >30 plant remains (cf. Bogaard et al. 2013a). Plant remains identified in sub-samples were multiplied up to estimate the total number of remains present.

2.1.4 Identifications

Identifications were primarily made using the reference collection housed in the Department of Archaeology, Durham University. Many common species from the Mediterranean flora are present within this collection, however, it does not contain comprehensive collections of wild/weed taxa which has limited some identifications to family or genus level. In particular, wild Poaceae spp. caryopses have typically not been identified to genus/species. Additional reference material was also gathered by the author in Spain and charred to produce comparative material. Towards the end of this PhD research, it was also possible to consult the reference collection housed in the Institute of Archaeology, University College London. Wild/weed taxa identified to family or genus were compared with a list of geographically relevant species from the *Flora de Aragón* to refine identifications where possible (Instituto Pirenaico de Ecología y Gobierno de Aragón 2005). Identification criteria outlined in archaeobotanical publications (Hillman et al. 1996; Hillman 2001) and seed atlases/manuals were also consulted (Fuller 2006; Jacomet 2006; Neef et al. 2011; Cappers et al. 2009, 2012). The prefix 'cf.' (compare) is used to designate less certain identifications. Nomenclature follows the *Flora Europaea* (Halliday and Beadle 1982). Latin and common names for cereals, millets, fruits/nuts, pulses, oil/fibre crops and other crops analysed in this PhD research are presented in Table 2.3. The appendices also contain Latin/common names for all plant remains identified. Throughout the text, the term 'cereals' is used to designate wheats *(Triticum* spp.), barleys (*Hordeum* spp.), oats *(Avena* spp.) and rye (*Secale cereal*e). The term 'millets' is used to designate the small-grained cereals, broomcorn millet (*Panicum miliaceum*) and foxtail millet (*Setaria italica*).

The identification criteria for some plant remains requires specific note. Free-threshing wheat species are separated based on rachis morphology (Hillman 2001), with the term 'bread wheat' referring to *Triticum aestivum*-type (hexaploid wheat), whilst 'durum wheat' refers to *T. durum*-

type (tetraploid wheat). Seeds of grass pea (*Lathyrus sativus*) and red pea (*Lathyrus cicera*) exhibit high morphological variability which makes separation of these two species problematic, although red pea seeds are typically smaller (cf. Nesbitt et al. 2017). Where the distinction between grass pea and red pea is unclear, the term 'grass/red pea' is used. Fruitstones of wild/sweet cherry (*Prunus avium*) and sour cherry (*Prunus cerasus*) are tentatively separated based on their morphology and size, with longer forms attributed to sweet cherry, although this distinction has not been possible in all cases (Burger et al. 2011).

Plant remains were quantified where possible by calculating the Minimum Number of Individuals (MNI), following methods adopted in other archaeobotanical studies (e.g. Jones 1991; Bogaard et al. 2013a; Fuller and Pelling 2018). Diagnostic elements were counted as one (e.g. embryo ends for cereal grains and pulse seeds, rachis nodes for free-threshing cereals, hooked ends for flax, stalks for grape pips etc.). Where fragmented, these plant remains were divided by 4 to provide MNI estimate. However, nutshell/fruitstone fragments are counted as individual fragments since it is difficult to provide an accurate MNI estimate for these remains. The original total counts are also presented in the Appendices. Charcoal fragments (>4mm), indeterminate charred fruit remains, rhizomes/tubers, small monocotyledon stems, cereal straw fragments (culms) and indeterminate/unidentified charred and mineralised remains were recorded semi-quantitively on an abundance scale: (+) = 1-5, + = 6-20, ++ = 21-50, +++ 50-100, ++++ = 100-500, +++++ = >500.

2.1.5 Preservation

At all the sites studied, plant remains were primarily preserved through charring. This is due to the semi-arid climate of the study region and charring is the most common mode of preservation for medieval sites in Spain/Portugal, especially in rural areas (Peña-Chocarro et al. 2019; cf. van der Veen 2007).

Limited evidence for desiccated plant remains was also noted at the sites studied in the Huecha Valley, comprising remains of elder and, to a lesser extent, blackberry, fig, grape and occasional wild/weed taxa. These do not appear to be modern intrusions (i.e. due to the absence of endosperms, recovery from secure contexts), though direct AMS ^{14}C dating would be necessary to confirm their date. It is well-established that remains of elder and raspberry are particularly decay resistant which may explain their presence (e.g. Moffett in Hedges et al. 1993:162-163; Zapata Peña and Ruiz-Alonso 2013; Speleers and van der Valk 2017). Desiccated plant remains have only been preserved in exceptional cases within the study region, such as within caves (e.g. Alcolea and Rodanés 2019) or within later medieval structures (e.g. Gerrard 2003:299).

A small quantity of uncharred plant remains were also preserved through biomineralisation and (phosphate) mineralisation (Shillito and Almond 2010). This included biomineralised Boraginaceae seeds and, in one case, hackberry fruitstones. These remains preserve due to the presence of biogenic carbonate in their pericarps, making them decay resistant (Shillito et al. 2009; Mathews 2010). Evidence for probable (phosphate) mineralisation was also identified at several sites. This mode of preservation only occurs in specific burial environments which contain high proportions of organic waste (e.g. latrines, midden/refuse deposits), causing the mineral replacement of organic plant tissues, typically by calcium phosphate (Green 1979; Carruthers 1991; McCobb et al. 2001, 2003; Marshall et al. 2008; Amichay et al. 2019). Mineralised plant remains were recovered from secondary contexts which probably incorporate material from several different sources, potentially including re-deposited material from middens/refuse deposits and possibly some material from latrines. This is discussed in more detail in the overview of the individual study sites (see Chapters 3 and 4). Mineralised plant remains are commonly recovered from medieval sites, especially latrines in urban sites, though they have also been recovered from 'rubbish' pits where they are probably re-deposited (e.g. Alonso 2005; Fuller and Pelling 2018; Ros et al. 2018).

2.1.6 Dating evidence

Dating evidence for the archaeobotanical assemblages was first established on the basis of stratigraphic relationships identified during excavations and pottery/artefactual evidence associated with samples. Pottery/artefactual evidence was directly associated with samples in many cases and this material was typically diagnostic of a specific period. Intrusive/residual remains are likely to be minimal since most sites did not contain multiple periods of occupation superimposed upon one another.

To confirm the dates of the archaeobotanical assemblages, direct AMS ^{14}C dates were also obtained on charred plant remains as part of this project (12 dates, from four sites). This dating strategy aimed to (i) target key samples/features associated with rich archaeobotanical assemblages or (ii) to establish phasing for the archaeobotanical assemblages. Single-entity samples of charred plant remains (cf. Ashmore 1999) were submitted to the Scottish Universities Environmental Research Centre (SUERC) Radiocarbon Dating Laboratory, Glasgow. Dates are calibrated using IntCal13 (Reimer et al. 2013) in OxCal v 4.2 (Bronk-Ramsey 2013) and are expressed at 95.4% probability.

2.2 Identifying crop husbandry practices I: crop-processing and arable weeds

The analysis of archaeobotanical weed assemblages can potentially provide a rich source of information for crop husbandry practices (Hillman 1981, 1984; Jones 2002). Different methodological approaches have been used to infer factors such as sowing times, the scale and intensity of cultivation, crop provenance, crop rotation and irrigation, amongst other factors (Jones et al. 2010). The basic premise of these approaches is that different crop husbandry practices will affect the composition of weed floras. Weed species have tolerances/preferences for specific ecological conditions and, by extension, cultivation conditions (Jones et al. 2010). Of particular relevance to this research is the use of weed assemblages to identify evidence for irrigation. Theoretically, irrigation may also be linked to other crop husbandry practices including the scale and intensity of cultivation (Halstead 2014:230-232).

2.2.1 Methodological framework

Irrigation and dry farming can significantly influence the composition of weed floras (e.g. Braun-Blanquet and de Bolós 1957; Guillerm and Maillet 1982; Miller 1982: 158-160; Jones et al. 1995; Charles and Hoppé 2003). Central to the interpretation of archaeobotanical weed assemblages is present-day ecological data gathered through the analysis of weed flora in rainfed and irrigated fields, particularly where 'traditional' flood irrigation is still used (Jones et al. 2005). In this respect, important surveys of weed flora in rainfed and irrigated fields have been undertaken in Wadi Ibn Hamad, southern Jordan (Charles and Hoppé 2003), and in Borja (Jones et al. 1995), one of the study regions under analysis here. An earlier survey of weed floras has also been undertaken within the broader study region of the Ebro basin (Braun-Blanquet and de Bolós 1957; Jones et al. 1995). Taken together, these studies identified differences in the weed flora between rainfed and irrigated fields, particularly where irrigation was of an intensive type (Jones et al. 1995; Charles and Hoppé 2003). This provides an important basis for the identification of irrigation using weed assemblages, however, extrapolating the results of present-day weed surveys to archaeobotanical datasets is challenging due to potential changes in the composition of weed floras through time and differences in crop husbandry practices (Hillman 1991; Jones 1992; Jones et al. 1995; cf. Guillerm and Maillet 1982; Cirujeda et al. 2011).

Different methodological approaches have been applied to interpret archaeobotanical weed assemblages. One approach examines the autecology of individual species, extrapolating the tolerances/preferences of modern weed species for certain environmental conditions to archaeobotanical assemblages (Jones 1992, 2002). For instance, irrigation may increase the frequency of species typical of damp/wet conditions in arid or semi-arid environments (e.g. Miller

1982: 158-160, 2011:65-66; Riehl 2010; Marston and Miller 2014). Similarly, irrigated fields may be managed more intensively, with the addition of manure, potentially causing an increase in species typical of disturbed and fertile habitats (Hillman 1973; Jones et al. 1999; Halstead 2014:230-232).

An alternative approach is phytosociology, the identification of plant communities (Küster 1991; Jones 1992). This approach classifies vegetation stands into syntaxa, hierarchical groupings of plant communities (class, order, alliance and association) based on their floristic composition, though the general habitat (e.g. a cereal field) is also considered. 'Character species' define a specific syntaxon. At the lowest syntaxonomic level of association, this approach has been successfully used to distinguish modern irrigated and rainfed fields in north-east Spain (Braun-Blanquet and de Bolós 1957). However, modern syntaxa cannot be directly applied to archaeobotanical research since plant communities are unlikely to have remained stable through time and weed assemblages may only contain a small proportion of the total number of species present (Hillman 1991; Behre and Jacomet 1991; Küster 1991; Jones 1992; Karg 1995; Bogaard 2004:5-7; Ernst and Jacomet 2006).

Despite this, phytosociology may provide an indication of the ecological tolerances/preferences of a species when analysed at the highest syntaxomic level of class (Jones 1992; Bogaard 2004:6). For example, species within the Secalinetea class have been associated with (rainfed) winter cereal crops, indicating their tolerance/preference for drier, little disturbed environments. In comparison, species within the Chenopodietea class have been associated with summer crops, gardens and irrigated areas, indicating their preference/tolerance for disturbed, fertile and slightly moister environments (Braun-Blanquet and de Bolós 1957; cf. Jones 1992; Jones et al. 1999). In the weed survey around Borja, species within the Chenopodieta class were also observed to be more frequent in irrigated fields, with a denser crop stand, opposed to rainfed fields (Charles and Jones pers comm. in Bogaard 2004:45).

However, it is difficult to make detailed inferences using the autecology and phytosociology since these approaches do not distinguish between the ecological tolerances and requirements which cause an individual species to grow (Charles et al. 1997; Jones 2002; Bogaard 2004:6). One approach which circumvents some of these problems is functional autecology, or Functional Interpretation of Botanical Surveys (FIBS) (Jones et al. 2005). This method measures the functional ecological attributes of weed species (e.g. leaf area, flowering onset period); attributes which enable a species to grow in certain ecological conditions. A detailed approach using FIBS is beyond the scope of this PhD research since plant functional attributes need to be directly measured in the field.

Applications of the FIBS approach to present-day weed floras in Wadi Ibn Hamad (Charles et al. 2003) and Borja (Charles et al. 1997) successfully distinguished irrigated and rainfed fields. Flowering time was one of the most important attributes, with species which finish flowering early in the season (a drought avoidance attribute) more frequent in rainfed fields (Jones et al. 1995; Charles et al. 2003; Jones et al. 2005). Water availability typically had a greater effect on weed floras than other factors such as field location, soil type, organic content or cultivation intensity (Jones et al. 1995; Charles et al. 2003). However, recent weed surveys across Morocco indicated that regional climatic variation, notably rainfall, obscured differences in weed species flowering time between irrigated and rainfed fields (Bogaard et al. 2018). This is unlikely to be a significant problem when comparing weed floras between sites in similar locations/regions.

Whilst flowering time is an important drought related attribute, it cannot provide conclusive evidence for irrigated or rainfed cultivation when used in isolation. A more detailed approach would also need to directly measure other drought tolerance attributes (e.g. tap root diameter, stomatal size, epidermal size/area) in modern irrigated/rainfed fields (Jones et al. 2005). For instance, wild oat (*Avena fatua*) finishes flowering early in the season (June), and in the recent past around Borja it was a particularly pernicious weed in rainfed fields, though it also occurs in irrigated areas (García Manrique 1960). Similarly, flowering time is also related to whether crops were spring or winter sown (Bogaard et al. 2001), as well as the intensity of cultivation, disturbance and fertility (Jones et al. 2000). Consequently, other functional attributes have also been considered where applicable. These attributes are used since this information can be obtained from local floras.

2.2.2 Analysis of weed assemblages

The identification of crop husbandry practices using weed assemblages requires careful sample selection (Hillman 1984; Jones 1991; Bogaard 2004; van der Veen 2007). Whilst most samples are likely to contain crop processing debris, weeds may derive from several origins including arable fields, dung burning, refuse, fuel, the surrounding environment and burnt mudbricks/rammed earth (Hillman 1981, 1984, 1991; Jones 1984; Miller 1984; Miller and Smart 1984; Smith 1998; van der Veen 1999, 2007; Spengler 2019). Similarly, samples may also contain crop species (and associated weeds) which did not grow together as well as a mix of different crop processing stages. Ethnoarchaeological research has demonstrated that different crop-processing stages can have a significant effect on the range of weed species present and introduce biases (Jones 1992).

Taken together, these factors may result in the co-occurrence of weed species in assemblages that did not actually grow together. Where samples contain material of mixed origin, the inferences which can be made about crop husbandry practices using weed seed data are limited (Bogaard 2004:60-67; McKerracher 2019:17).

To determine whether wild/weed taxa present reflect arable weeds, the composition of assemblages has been examined on a sample-by-sample basis together with an assessment of the potential formation processes (Hillman 1984; Jones 1991; van der Veen 2007). Samples were classified according to whether they contain material from one source/event or a mixture of different sources/events. This classification was based firstly on whether a sample is dominated by a single crop type (e.g. free-threshing cereals, pulses) and secondly whether a sample is dominated by a single crop species (e.g. durum wheat, lentils). Weeds were only considered to be directly associated with a specific crop if (arbitrarily) ≥70% of the remains derive from a single crop species (cf. Bogaard 2004: 64). Whilst it is recognised that a sample containing a mixture of hulled barley and free-threshing wheat could reflect a maslin (Jones and Halstead 1995), it cannot be assumed that these crops were actually cultivated together under the same conditions. Sample compositions were therefore classified as dominated by a specific crop species (e.g. 'hulled barley dominant') or as 'mixed', provided that they contained at least 30 charred crop remains. This data is presented for each sample in Appendices 1, 2, 3, 6, 8, 9, 11, 12 alongside the full archaeobotanical dataset.

Nearly all the samples analysed in this PhD research are classified as 'mixed' (see Chapters 3 and 4), and consequently it is suggested that the analysis of weed assemblages in broad terms at the site-level is more appropriate, as opposed to the sample-level. Whilst the weeds within these mixed samples probably derive from more than one source, they can still provide generalised information on the nature of cultivation conditions, particularly where they are associated with comparatively rich assemblages of crop processing debris (e.g. grains, rachises, culm nodes). Potential arable weeds may be identified based on their ecological tolerance/preferences and flowering onset period, since weeds which set seed when crops ripen may be harvested together with the crop (Charles 1998).

Weed ecological data and the functional attributes analysed were gathered from the *Flora de Aragón* (Instituto Pirenaico de Ecología y Gobierno de Aragón 2005). Other floras were also examined for comparison including the *Flora manual dels Països Catalans* (Bolós et al. 2005) and the *Flora Iberica* (Castroviejo 1986-2014). Table 2.4 provides a summary of the weed ecological data and functional attributes used in this PhD research. This primarily includes wild/weed taxa identified to species, though some taxa identified to genus are included in cases where only species with similar ecological tolerances/preferences and growth patterns are present (e.g. *Setaria verticillata/viridis*). In other cases, wild/weed taxa identified to genus which include species with widely different growth patterns and ecological tolerances/preferences are excluded (e.g. *Rumex* spp., Poaceae spp.).

2.3 Identifying crop husbandry practices II: stable isotope analysis

Recently, stable carbon isotope analysis ($\delta^{13}C$) has been widely applied in archaeological research as a novel method for directly identifying the cultivation conditions of specific crops (Fiorentino et al. 2015; Lodwick and Stroud 2019). It is well-established that $\delta^{13}C$ ratios in plants with a C_3 photosynthetic pathway (e.g. cereals, legumes) are strongly influenced by environmental conditions, especially water availability (O'Leary 1988; Diefendorf et al. 2010; Kohn 2010). Consequently, the method has been used to provide evidence for crop provenance (e.g. Heaton et al. 2009 Fiorentino et al. 2012), climatic fluctuations/droughts (e.g. Riehl et al. 2014) and crop husbandry practices, including irrigation (e.g. Araus and Buxó 1993; Araus et al. 1997a, 1999, 2007, 2014; Ferrio et al. 2005; Aguilera et al. 2008; Riehl et al. 2008; Masi et al. 2014; Wallace et al. 2015; Styring et al. 2017; Bogaard et al. 2018).

2.3.1 Methodological framework

2.3.1.1 RELATIONSHIP BETWEEN WATER AVAILABILITY AND STABLE CARBON ISOTOPE RATIOS

Plant stable carbon isotope ratios primarily reflect a plants' photosynthetic pathway (C_3, C_4, CAM), the $\delta^{13}C$ value of atmospheric CO_2 and environmental conditions, especially water availability (O'Leary 1988; Dawson et al. 2002). For C_3 plants, the relationship between water availability and $\delta^{13}C$ ratios is methodologically well established and this is normally expressed as carbon isotope discrimination (Δ) in plant sciences. $\Delta^{13}C$ reflects changes in plant isotopic composition independently of variation in the $\delta^{13}C$ value of atmospheric CO_2 ($\delta^{13}C_{air}$). This is calculated following Farquhar et al. (1989):

$$\Delta^{13}C = (\delta^{13}C_{air} - \delta^{13}C_{sample}) / (1 + \delta^{13}C_{sample})$$

During photosynthesis plants assimilate atmospheric CO_2 through stomata (O'Leary 1981; Farquhar et al. 1982; Farquhar et al. 1989). This process discriminates against the heavier isotope ^{13}C, opposed to the lighter isotope ^{12}C (Farquhar et al. 1989). The degree of ^{13}C discrimination is strongly controlled by the opening and closing of plant stomata (stomatal conductance), which in turn is closely linked to water availability (Farquhar and Sharkey 1982). Under optimal conditions (i.e. higher water availability), stomata remain 'open' allowing atmospheric CO_2 to diffuse into their leaves, causing maximum ^{13}C discrimination, i.e. a higher $\Delta^{13}C$ value (Farquhar et al. 1989). However, under low water availability stomata 'close', restricting the diffusion of atmospheric CO_2 into leaves, causing less ^{13}C discrimination, i.e. a lower $\Delta^{13}C$ value (Farquhar et al. 1989). The 'closure' of stomata is a physiological response by the plant to restrict water loss (Farquhar et al. 1989). In comparison to C_3 plants, there is no clear relationship between water availability and ^{13}C discrimination in C_4 plants such as millets (Farquhar 1983; Flohr et al. 2019).

Variation in $\Delta^{13}C$ values can be potentially caused by a wide range of environmental and biological factors including salinity, temperature, nutrient availability, light intensity and altitude (e.g. O'Leary 1991; Farquhar et al. 1982; Körner et al. 1988, 1991; Tieszen 1991; Condon et al. 1992; Peñuelas et al. 1997; Heaton et al. 1999; Dawson et al. 2002; Shaheen and Hood-Nowotny 2005; Cernusak et al. 2013). However, it has been widely demonstrated that water availability is the most influential factor determining $\Delta^{13}C$ values in arid/semi-arid environments (e.g. Chaves et al. 2002; Diefendorf et al. 2010; Kohn 2010; Hartman and Danin 2010; Prentince et al. 2011). Water availability is primarily correlated with rainfall, though it is also affected by other related variables including soil depth, soil type, topography, temperature, wind speed, evapotranspiration rates, competition from weeds and seasonality amongst other factors. Whilst environmental factors strongly determine water availability and therefore $\Delta^{13}C$ values, the impact of this may to some extent be overridden by crop husbandry practices such as the cultivation of naturally wetter soils or irrigation (Wallace et al. 2013; Riehl et al. 2014; Flohr et al. 2019).

Alongside $\Delta^{13}C$ values, stable nitrogen isotope analysis ($\delta^{15}N$) has also been used to identify evidence for manuring (Fiorentino et al. 2015). The interpretation of plant $\delta^{15}N$ values in Mediterranean regions is complicated by the fact that aridity (and salinity) can significantly increase $\delta^{15}N$ values (Styring et al. 2016a; Bogaard et al. 2018). This can make it difficult to disentangle the effect of manuring from aridity, though a baseline $\delta^{15}N$ value from wild herbivore collagen may help to resolve this. Similarly, charred cereal grains can have low %N in some cases, making measurements of $\delta^{15}N$ unreliable. Consequently, $\delta^{15}N$ analysis has not been undertaken for this PhD research.

2.3.1.2 RELATIONSHIP BETWEEN IRRIGATION AND CROP $\Delta^{13}C$ VALUES

The relationship between irrigation and $\Delta^{13}C$ values in cereals has been widely examined in agronomic research (e.g. Craufurd et al. 1991; Febrero et al. 1994; Teulat et al. 2001; Merah et al. 1999, 2002; Araus et al. 2003; Monneveux et al. 2004, 2005, 2006; Jiang et al. 2006; Tambussi et al. 2007; Rizza et al. 2012). This provides a basis for understanding the relationship between irrigation and grain/chaff $\Delta^{13}C$ values, however, these studies cannot necessarily be directly applied to archaeological research. Modern agronomic studies typically use modern cultivars which have been specifically selected to perform better (i.e. semi-dwarf varieties, earlier/uniform ripening, higher yields) and consequently there can be large (c.>1‰) variation in $\Delta^{13}C$ values compared to 'traditional' landraces (Araus et al. 1997b, 2006; Merah et al. 1999; Voltas et al. 1999; Royo et al. 2008; Heaton et al. 2009; Khazaei et al. 2010; Bogaard et al. 2016; Fiorentino et al. 2015). To interpret archaeological data accurately it is necessary to gather a large quantity of reference $\Delta^{13}C$ data for landraces, from both controlled experiments and 'traditionally' managed farms (Fiorentino et al. 2015). Currently only a small number of studies focusing on applications to archaeological research have been undertaken (Araus et al. 1997a, 1997b, 2003; Wallace et al. 2013; Flohr et al. 2019). These studies have primarily focused on hulled barley and free-threshing wheats (bread wheat, durum wheat), with little/or no comparative work undertaken for glume wheats (e.g. emmer wheat), rye and pulses.

Cereal grain $\Delta^{13}C$ values are strongly linked to water availability during the grain filling period (Araus et al. 1997a, 2003; Ferrio et al. 2005; Flohr et al. 2019). However, water availability before grain filling has also been shown to affect $\Delta^{13}C$ values (Wallace et al. 2013; Flohr et al. 2019). This may be due to the retention of water in the soil for long-periods and/or it may reflect the carbon sources contributing to grain filling (Wallace et al. 2013). Two sources of carbon can contribute to grain filling: assimilates acquired through photosynthesis or the remobilisation of stored assimilates (Merah et al. 2002; Yang and Zhang 2006; Merah and Monneveux 2015). Remobilised stored assimilates can significantly contribute to grain filling under low water availability; April/May droughts during grain filling are common throughout the Mediterranean (Merah and Monneveux 2015). Assimilates acquired in earlier stages of growth, when water availability was higher (i.e. due to rainfall or irrigation), may have a higher $\Delta^{13}C$ value (Merah and Monneveux 2015). Overall, grain $\Delta^{13}C$ values probably reflect water availability over a long growth period, rather than the relatively short grain-filling period (Wallace et al. 2013; Flohr et al. 2019). A comparison between grain and chaff $\Delta^{13}C$ values may provide an indication of water availability earlier in the growing season (Merah et al. 2002; Wallace et al. 2013).

Very little data is available for pulses such as broad beans or lentils (Araus et al. 1997a; Wallace et al. 2013; Bogaard et al. 2018). As with cereals, a positive relationship between water availability and $\Delta^{13}C$ values has been observed in pulses, though they are thought to be more sensitive to drought stress (cf. Khan et al. 2007). The interpretation of pulse $\Delta^{13}C$ values can be complicated by the fact they ripen indeterminately and pods may be harvested at different stages throughout the growing season.

2.3.1.3 INTERPRETING ARCHAEOBOTANICAL $\Delta^{13}C$ VALUES

Different interpretative models have been used to identify irrigation/drought stress in cereal remains using $\Delta^{13}C$ values (Table 2.5). Wallace et al. (2013) have developed a broad framework using evidence from their own research and other studies across Mediterranean regions with data from controlled experiments and farm studies. This framework has been used in several subsequent studies (Bogaard et al. 2013b, 2018; Vaiglova et al. 2014a; Wallace et al. 2015; Nitsch et al. 2017, 2019a; Vignola et al. 2017; Styring et al. 2017; Alagich et al. 2018). Wallace et al. (2013) distinguish three broad bands to *approximate* water-status: 'poorly watered', 'moderately watered' and 'well-watered' for free-threshing wheat, hulled barley and lentils (Wallace et al. 2013). 'Poorly watered' free-threshing wheat and hulled barley grains $\Delta^{13}C$ values are <16‰ and <17.5‰ respectively, whereas 'well-watered' wheat and barley $\Delta^{13}C$ values are >17‰ and >18.5‰ respectively, with intermediate 'moderately watered' values (Wallace et al. 2013). $\Delta^{13}C$ values for free-threshing wheat rachis segments were on average +1.7‰ higher than the corresponding grain (data not presented in Table 2.5). Water-status bands for lentils were similar to wheat (Wallace et al. 2013).

This framework proposed by Wallace et al. (2013) is comparable to other research. Riehl et al. (2014) suggests a similar $\Delta^{13}C$ value for 'poorly watered' hulled barley, with values between 16-17‰ and below indicating increasing drought stress. Similarly, Araus et al. (1997a) suggested irrigated durum wheat and hulled barley $\Delta^{13}C$ values are typically >17.5‰ and >18‰ respectively.

Recently, Flohr et al. (2019) have re-assessed the framework proposed by Wallace et al. (2013) through controlled experiments in Jordan using durum wheat and 6-row hulled barley. Flohr et al. (2019) proposed the use of more conservative cut-off points (i.e. only interpreting extreme values), between 'poorly watered' and 'well-watered'. Following Flohr et al. (2019), 'well-watered' free-threshing wheat grain and hulled barley grain values are >17.6-18‰ and >18.5-19‰ respectively, whilst 'poorly watered' values for free-threshing wheat and hulled barley are c.<15‰ and <16.5‰ respectively. Flohr et al. (2019) note that the differentiation between 'poorly watered' and 'moderately watered' bands proposed by Wallace et al. (2013) may be ambiguous in some cases, particularly for free-threshing wheat.

Figure 2.2 summarises cereal grain $\Delta^{13}C$ values for free-threshing wheat grains and hulled barley grains using data from a range of studies across semi-arid environments in the Mediterranean. Some of these studies have been previously cited (and used) in the framework developed by Wallace et al. (2013), although Figure 2.2 also includes data from additional studies. Overall, there is a separation between $\Delta^{13}C$ values between rainfed and irrigated samples. For free-threshing wheat, irrigated samples are typically c.>17‰, whereas rainfed samples typically fall between c.15-17‰. However, as identified by Flohr et al. (2019), there is very large variation in irrigated free-threshing wheat $\Delta^{13}C$ values. For hulled barley, irrigated samples are typically c.>18.5‰, whilst rainfed samples are typically c.<18.5‰. Most rainfed hulled barley grains fall within the range c.15-17‰. The median $\Delta^{13}C$ value for both rainfed free-threshing wheat and hulled barley is c.16‰. The separation between rainfed and irrigated samples is clearer for hulled barley than free-threshing wheat. The location of the 'cut-off' points for irrigated free-threshing wheat and hulled barley are directly comparable to the framework proposed by Wallace et al. (2013), and similar to those suggested by other researchers (Table 2.5).

The large overlap between rainfed and irrigated samples in Figure 2.2 may be attributed to several factors. This could include genotypic variation between landraces, different crop husbandry practices (i.e. weeding, fallowing), different soil types or annual fluctuations water availability (i.e. abnormally high rainfall); all these factors could cause 'anomalous' $\Delta^{13}C$ values. Consequently, Figure 2.2 provides an indication of the potential range of variation in $\Delta^{13}C$ values which *may* be expected between rainfed and irrigated cultivation regimes in semi-arid environments[2]. Due to this potential variability, the interpretation of $\Delta^{13}C$ values should be limited to 'high' and 'low' values, as suggested by Flohr et al. (2019).

Other factors should also be considered when interpreting cereal grain/rachis $\Delta^{13}C$ values:

i) Inter-ear/plant and inter-plot/field variation in grain and rachis $\Delta^{13}C$ values has been shown to be small, typically ±0.3-1.3‰ (Heaton et al. 2009; Wallace et al. 2013; Riehl cited in Fiorentino et al. 2015; Flohr et al. 2019). Consequently, when there is large variation in $\Delta^{13}C$ values for a specific crop species (>1‰), this may indicate that the grains were cultivated under different regimes (i.e. rainfed versus irrigated), different fields or different years.

ii) There is natural variation in $\Delta^{13}C$ values between free-threshing wheat and hulled barley grains when cultivated under the same conditions. Bread wheat and durum wheat have similar $\Delta^{13}C$ values, whilst emmer wheat is also thought to be similar (Wallace et al. 2015). In comparison, hulled barley has a higher $\Delta^{13}C$ value than wheats, with potential differences c.+1‰ for 2-row types and c.+2‰ for 6-row types (Voltas et al. 1999; Jiang et al. 2006; Aniya et al. 2007). Therefore, if free-threshing wheat has a higher $\Delta^{13}C$ value

[2] The relationship between cereal $\Delta^{13}C$ values and water availability is different for arid environments (Flohr et al. 2019).

than hulled barley, this indicates that barley has been cultivated under drier conditions and vice versa.

iii) $\Delta^{13}C$ values in free-threshing wheat rachis segments should support the interpretation of the corresponding grain $\Delta^{13}C$ values. Rachis segments have a higher $\Delta^{13}C$ value than grain, c.+1.7-2‰ (Merah et al. 2002; Wallace et al. 2013).

As noted above, very little research has examined the relationship between irrigation and $\Delta^{13}C$ values in pulses (Table 2.6). There can be large variation in $\Delta^{13}C$ values for lentils and broad beans when cultivated under rainfed and irrigated conditions. Overall, the cut-off point between irrigated and rainfed samples is >17-18‰ (cf. Wallace et al. 2013). Comparative data from a sub-humid environment in northern Morocco which receives high rainfall (703mm) similarly suggests that pulses cultivated in high water-availability have $\Delta^{13}C$ values c.>17-18‰ (Bogaard et al. 2018).

2.3.1.4 CLIMATIC VARIATION OR IRRIGATION?

The identification of rainfed versus irrigated agriculture requires a comparison with climatic records. The present-day climate of north-east Spain is semi-arid and rainfed cereal cultivation is possible in most areas. However, high evapotranspiration rates and erratic winter-spring rainfall can lead to severe droughts, causing either crop failure or severely limiting crop growth (Halstead 2014:230-232). Higher and more reliable yields may be obtained from irrigated cereals (Halstead 2014:230-232, 241). Whilst present-day climatic conditions differ from the medieval period, there is little evidence that crop water availability has *significantly* changed based on palaeoclimatic records. In the early medieval period (c.6th-9th/10th CE), cooler and wetter conditions can be identified, although documentary sources also point to severe droughts in this period, especially in the 8th and 9th centuries (Domínguez-Castro et al. 2014; Sánchez-López et al. 2016). The Medieval Climate Anomaly (MCA) between the 9th/10th to 13th century was in turn generally characterised by a shift to a warmer, more arid climate, although some record regional heterogeneity and climatic oscillations between wet/dry intervals (Mann and Jones 2003; Mann et al. 2008, 2009; Moreno et al. 2011, 2012; Corella et al. 2013; Barreiro-Lostres et al. 2014; Cook et al. 2016; Sánchez-López et al. 2016; Büntgen et al. 2017; Lüning et al. 2019; López-Blanco and Romero-Viana 2019). The subsequent transition from the MCA to the Little Ice Age (LIA), c.1300-1400, was accompanied by a widely oscillating climate, with a general trend towards a cooler and wetter climate, yet severe weather-events and droughts are also recorded (Barreiro-Lostres et al. 2014; Oliva et al. 2018; Barriendos et al. 2019; López-Blanco and Romero-Viana 2019). As in present-day agricultural systems, water availability is likely to have been one of the main limiting factors on crop growth throughout the medieval period.

A challenge for archaeobotanical research is inferring whether variation in crop $\Delta^{13}C$ values between samples from the same period or between sites of different periods reflects irrigation, cultivation in naturally wetter soils or climatic change (i.e. increased rainfall, abnormally dry/wet years). It has been suggested that the analysis of wood charcoal $\Delta^{13}C$ values, especially in pine, can corroborate crop $\Delta^{13}C$ values (e.g. Ferrio et al. 2007), however, this approach assumes that (i) pine charcoal and crops are contemporary with one another, and that pine grew in the same environment as cereal fields. For example, in the Huecha Valley, pine (*Pinus* spp.) currently only grows at higher altitudes, where the climate is notably cooler and wetter, compared to the lowland, more arid areas where cereals are cultivated. Similarly, crop $\Delta^{13}C$ values reflect *annual* water availability, whereas charcoal $\Delta^{13}C$ values reflect a composite of up to several years. To some extent, the problems of weather/climatic changes can be mitigated against by analysing a large number of samples which potentially derive from different ears, plants, fields and years. Similarly, interpretations of crop $\Delta^{13}C$ values may be strengthened through comparison with weed seed data (Bogaard et al. 2016, 2018) and the analysis of irrigation systems where they are well-understood (e.g. Gerrard 2011; Gerrard and Gutiérrez 2018a).

2.3.1.5 IMPACT OF CHARRING AND CONTAMINATION

The impact of charring and contamination on the interpretation of crop $\Delta^{13}C$ values also needs to be considered. Charring experiments suggest low temperature charring causes a very small increase in cereal grains and pulse seeds $\Delta^{13}C$ values, +0.11‰ (Nitsch et al. 2015). For archaeological samples, the charring temperatures are unknown, though an approximation of charring conditions can be obtained by assessing the preservation level of cereal grains and pulse seeds. Morphologically well preserved and undistorted cereal grains are thought to be produced under a relatively narrow range of conditions: low temperatures (c.220-260°C) and a reducing/oxygen poor environment (Boardman and Jones 1990; Braadbaart and van Bergen 2005; Braadbaart et al. 2005; Braadbaart 2008; Charles et al. 2015; Berihuete-Azorín et al. 2019). By assessing the overall level of preservation, an indication of charring temperatures may be obtained. Consequently, for very well preserved, undistorted grains/seeds there is likely to be minimal offset in $\Delta^{13}C$ values due to charring.

Contamination during burial may cause small variation in $\Delta^{13}C$ values (Vaiglova et al. 2014b; Brinklemper et al. 2018). However, pre-treatment methods designed to remove potential contaminants can significantly reduce sample size and also alter the original $\Delta^{13}C$ value of the sample (Vaiglova et al. 2014b; Brinkkemper et al. 2018). Various studies have reported no significant and consistent differences between $\Delta^{13}C$ values in pre-treated and non-treated samples (Lightfoot and Stevens 2012; Styring et al. 2016b; Aguilera et al. 2018; Brinkkemper et al. 2018). Brinkkemper et al. (2018) indicate that reliable $\Delta^{13}C$ measurements may be obtained from un-treated samples recovered through flotation which are manually cleaned of visible adhering sediment.

2.3.1.6 VARIATION IN ATMOSPHERIC CO_2

Changes in the $\delta^{13}C$ value of atmospheric CO_2 ($\delta^{13}C_{air}$) throughout the Holocene need to be corrected for when comparing modern and archaeological plant $\Delta^{13}C$ values. The $\delta^{13}C_{air}$ of air has decreased from c.-6‰ *c.*10 000ya to a present-day value of *c.*-8‰ and an *estimate* of $\delta^{13}C_{air}$ throughout the Holocene can be obtained from ice core records using the AIRCO2_LOESS system (Ferrio et al. 2005). The effect of changes in the pressure of atmospheric CO_2 (*p*CO2) on plant $\Delta^{13}C$ values are uncertain throughout the Holocene, though it is unlikely to cause large variation (i.e. *c*. <0.5‰) in plant $\Delta^{13}C$ values (Schubert and Jahren 2012; Kohn 2016; Hare et al. 2018). In general, changes in *p*CO2 throughout the Holocene are not corrected for archaeological datasets (e.g. Araus et al. 1997a; Bogaard et al. 2013b; see however Mora-González et al. 2019a).

2.3.2 Sample selection and preparation

The archaeobotanical assemblages from each site were examined carefully to assess whether they were suitable for stable carbon isotope analysis based on the following criteria: (i) they contain large and very well-preserved assemblage of cereal grains, chaff and/or pulse seeds; (ii) the contexts were directly AMS ^{14}C dated, or associated with a directly dated context.

In total, 290 single-entity samples were submitted for stable carbon isotope analysis from four sites (Table 2.7). The samples are all charred and include 231 cereal grains, 24 cereal rachis segments and 35 pulse seeds. Free-threshing wheat and hulled barley grains were targeted for analysis since these were the most common cereal species recorded at all sites and most present-day research has examined these species. Millets have not been analysed since there is no clear relationship between irrigation and C_4 plants (Flohr et al. 2019).

Each sample analysed is an individual cereal grain, rachis segment or pulse seed. This methodology is in contrast to other approaches which have used bulk-samples of c.10 grains/seeds (e.g. Vaiglova et al. 2014b; Wallace et al. 2015; Nitsch et al. 2015, 2017, 2019a; Styring et al. 2016, 2017; Alagich et al. 2018; Bogaard et al. 2018). By analysing bulk-samples, variability in $\Delta^{13}C$ values is reduced (Nitsch et al. 2015; Flohr et al. 2019: ESM3). However, a single-entity approach is used here to avoid combining samples which were potentially cultivated in different fields, using different crop husbandry practices or during different years. Single-entity approaches have been used in other studies (e.g. Masi et al. 2014; Riehl et al. 2014; Gron et al. 2017; Mora-González et al. 2016, 2018, 2019a, b; O'Connell et al. 2019). Previous research suggests that it is necessary to analyse 5-10 charred plant remains, or preferably more, per context to achieve accurate results (Reihl et al. 2014; Nitsch et al. 2015; Flohr et al. 2019). A minimum of 5 charred plant remains were analysed per context, though in most cases a larger number of samples were analysed.

The dimensions of each sample were measured, and the level of preservation/distortion recorded. For cereal grains an adapted version of the preservation/distortion scale outlined by Hubbard and al-Azm (1990) was followed and this was extended to include rachis segments and pulse seeds. In the Hubbard and al-Azm (1990) scale, preservation and distortion are recorded separately, however the two variables are linked (Charles et al. 2015) and therefore an adapted preservation ('P') scale is used (Table 2.8). This scale only provides a subjective indication of the level of preservation and there can be inter-observer variation when assigning a 'P' number, with some samples falling into intermediate categories (i.e. 'P2/P3'). Theoretically, the scale outlined in Table 2.8 correlates with charring temperatures, though it is important to note that mechanical damage during sampling and recovery will also alter the preservation level. The samples submitted for stable isotope analysis were generally in an excellent state of preservation: 80% = P1/P2, 3% = P2/P3, 17% = P3.

Due to the excellent preservation, a change in $\Delta^{13}C$ values due to charring is therefore likely to be minimal. An offset of +0.11‰ recommended by Nitsch et al. 2015 has not been applied since the precise offset is highly dependent on charring temperature and this can only be approximated for archaeological samples. In addition, it is important to note that the outer epidermis/testa (seed coat) for cereal grains and pulses was either intact or near-intact. In cereal grains, there is a 0.4-1‰ difference in $\Delta^{13}C$ values between the epidermis and endosperm (Heaton et al. 2009; Flohr et al. 2019), whilst in pulse seeds there may be a 2‰ difference in $\Delta^{13}C$ values between the testa and cotyledon (Treasure et al. 2016).

The samples were generally very clean (i.e. minimal/no adhering sediment) and contamination is likely to be minimal. Where sediment was present adhering to a sample, this was gently removed by scraping with a scalpel. Samples were not pre-treated since reliable $\Delta^{13}C$ values can be obtained from untreated samples (Brinkkemper et al. 2018) and the impact of different pre-treatment strategies on the original $\Delta^{13}C$ value is unclear. Each sample was homogenised in an agate pestle and mortar, with equipment cleaned between samples.

2.3.3 *Stable Isotope Analysis*

Stable isotope measurements and total organic carbon content of the samples were undertaken in the Stable Isotope Biogeochemistry Laboratory (SIBL) at Durham University using a Costech Elemental Analyser (ECS 4010) connected to a Thermo Scientific Delta V Advantage isotope ratio mass spectrometer. Carbon isotope ratios are corrected for ^{17}O contribution and reported in standard delta (δ) notation in per mil (‰) relative to Vienna Pee Dee Belemnite (VPDB). Isotopic accuracy was monitored through routine analyses of in-house standards (glutamic acid, $\delta^{13}C$ = −11‰; urea, $\delta^{13}C$ = −43.3‰; spar calcite, $\delta^{13}C$ = 2.9‰), which were stringently calibrated against international standards (eg, USGS40, USGS24, IAEA-600): this provided a linear range in $\delta^{13}C$ between −44‰ and 3‰. Analytical variation in carbon isotope analyses was typically ±0.1‰ for replicate analysis of the international standards and <0.2 ‰ on replicate sample analysis. Total organic carbon was obtained as part of the isotopic analysis using an internal standard (Glutamic Acid, 40.82% C).

2.3.4 *Interpretation of data*

Following the discussion outlined above, this PhD research uses an adapted version of the frameworks proposed by Wallace et al. (2013) and Flohr et al. (2019) to interpret crop $\Delta^{13}C$ values (Tables 2.5-2.6). Two levels of water-status are used: 'poorly/moderately watered' probably reflecting rainfed cultivation, and 'well-watered' probably reflecting irrigation. It is important to emphasise that these 'bands' only *approximate* water-status.

3 Teruel case-study area (Islamic sites, 10th-12th centuries)

This chapter presents the archaeobotanical evidence for the two rural Islamic (10th-12th century) sites examined in Teruel: Cabezo de la Cisterna (Alba del Campo) and El Quemao (Sarrión). The crop isotope evidence is also presented for El Quemao. The sites were investigated as part of the project 'Husun y Qura: Estudio del poblamiento andalusí' which is examining rural Islamic settlements in the wider Teruel region through survey and excavation (Villagordo Ros 2018).

3.1 Regional setting

3.1.1 Present-day climate and topography

Both the study sites are situated within the present-day region of Teruel in the south of Aragón (Figure 3.1). The physical geography of this region is dominated by the extensive uplands of the Iberian System; a major mountain range effectively forming a barrier between the Ebro Valley and other areas of Spain. Two of the most important valleys cutting through this mountain range are the Jalón and Jiloca, which together form the Calatuyud-Daroca-Teruel Depression. This area of land between c.600m and 1200m (a.s.l.) links the Ebro Valley to central areas of Spain in the west, also forming a natural communication route to the Mediterranean coast in the east.

In comparison to the cold semi-arid climate of the Ebro Valley (Köppen–Geiger zone BSk), Teruel is primarily characterised by a temperate oceanic climate (Köppen–Geiger zone Cfb). This is largely a reflection of its high altitude, though in the river valleys which dissect the region the climate becomes increasingly arid, especially in more southerly areas around the city of Teruel. Cabezo de la Cisterna is situated at the transition between these two climatic gradients, whilst El Quemao is within a more arid setting. Though both sites are situated at comparatively high altitudes (1000-1100m a.s.l.), mean annual rainfall is still low, averaging c.400-500mm annually. Temperatures can fluctuate widely, winter temperatures potentially reaching -20^{o}C (average 0-2^{o}C in January), whilst summer temperatures can be as high as c.40^{o}C (average 20-22^{o}C in July) (Iberian Climate Atlas 2010; AEMET 2019). Consequently, droughts are a common occurrence. Extensive woodlands cover the Iberian System and these are dominated by Meso-Mediterranean species, especially pines (*Pinus* spp.) and holm oak (*Quercus ilex*).

Traditionally, agriculture in the region has been characterised by transhumance and the rainfed cultivation of wheat, barley, rye and oats (Moreno García 1997; Pinilla 2006). The sites examined here are situated in areas which are today devoted towards the extensive rainfed cultivation of cereals. However, the small river valleys which cut through the region are potentially irrigable and small irrigated areas exist around many modern villages and towns.

3.1.2 Historical and archaeological context

The study area examined was broadly situated at the intersection between three political/geographical regions of al-Andalus: the Middle March around Toledo, the Upper March around Zaragoza and the Eastern March around Valencia (Cervera Fras 1989; Bosch Vilá 1998; Torró 2012). Though the limits these 'March' regions are poorly defined, the Eastern March spanned along the Mediterranean coast from Tortosa in the north to Almería in the south (Torró 2012). The sites examined here broadly fall within this Eastern March, particularly in the case of El Quemao, emphasising their connections with Valencia and the Mediterranean coast (Guichard 2001:217).

Following the Islamic conquests, this region is thought to have been predominantly settled by Berber communities, following toponymic and documentary evidence (Bosch Vilá 1959; Guichard 1976; Ṭāha 1989:173-174; Manzano Moreno 1991; Catlos 2004:25-27; Olmo Enciso 2011; Sarr 2013). Until the 11th century, it was (at least nominally) under the control the Umayyad state from Córdoba, however, with the break-up of al-Andalus during the Taifa period, two small kingdoms emerged in Alpuente and Albarracín (Bosch Vilá 1959; Viguera Molíns 1994:81-84). The Taifa of Albarracín was an important and powerful kingdom within al-Andalus, whilst little is known about the comparatively small Taifa of Alpuente (Viguera Molíns 2010:27-30). These Taifa kingdoms controlled the region until the arrival of Berber ruling dynasties from North Africa, the Almoravids and Almohads, in the 11th-12th centuries (Fierro 2010:72; Viguera Molíns 1994:127-128). During this period, the region was closely tied to Valencia (Guichard 2001:472). The Christian conquests in the final decades of the 12th century (Teruel was captured in 1170) brought an end to Islamic rule, though Valencia itself was not conquered until the 13th century (Kennedy 1996).

Numerous archaeological studies have examined rural settlements in areas of the Eastern March, especially around Valencia (Eiroa Rodríguez 2012). However, very little research has been undertaken within more inland areas in Teruel and documentary sources also provide limited information. In general, the region does not appear to have been densely settled and there were no major cities, though minor urban centres such as Albarracín did grow in importance (Bosch Vilá 1959; Navarro Espinach 1999). Where archaeological research has been undertaken, the settlements identified appear to primarily comprise *burjs* (small fortified towers) and *alquerías* (hamlets/farmsteads) alongside *hisn*/pl. *husun* (fortified refuges); these *husun* are comparatively small in comparison to other, more urbanised areas of al-Andalus (Ortega Ortega 1997; Laliena Corbera 2007:142-144). Near to the study site of El Quemao, a *hisn* is referred to in documentary sources at Sarrión, though no archaeological remains have been identified (Guichard 2001: 297; Ortega Ortega 2004:86). Many of these rural settlements are thought have been abandoned following the Christian conquests (cf. Laliena Corbera 2007).

3.2 The sites: archaeobotanical and crop isotope evidence

3.2.1 Cabezo de la Cisterna, Alba del Campo (11th-12th centuries)

Cabezo de la Cisterna is situated on a small, steep sided hill c.5km south-west of the town of Alba del Campo (Figure 3.2). This area of high altitude (1130m a.s.l.) forms the upper section of the Jiloca Valley, a tributary of the River Jalón. The modern landscape consists of a patchwork of rainfed cereal fields.

The site is a small, fortified rural Islamic settlement, with archaeological remains comprising a fortified tower, a perimeter wall, a water cistern and several structures/houses. The surrounding area is rich in iron ore and the settlement may be related to mining activity (Rico et al. 2005; Ortega Ortega 2008). It is also situated on an important communication route between the Jiloca Valley, the Sierra de Albarracín to the south and the Sierra Menera to the north-west.

Between 2015 and 2016, small-scale excavations were undertaken at the site as part of the project *Husun y Qura: Estudio del poblamiento andalusí*, targeting the fortified tower in the centre of the site and occupation areas on its edge (Villagordo Ros 2015, 2016). Through collaboration with this project in the 2016 excavation season, bulk-sampling was undertaken on occupation deposits associated with two houses/rooms (Area 1 and Area 3) as part of this PhD (Figures 3.3-3.4). The excavated deposits contained background waste typical of occupation (e.g. charcoal, ash, pottery, faunal remains) and large rotary quern was identified in Area 3. Pottery recovered from the houses places the abandonment of the site at the end of the 11th to early 12th century (Villargordo Ros 2015, 2016).

3.2.1.1 SAMPLING

Overall, 17 small samples were collected from multiple locations within the occupation deposits, with the aim of reaching a total sample volume of 40-60L per context. The total sample volume is 157L (Table 3.1).

3.2.1.2 ARCHAEOBOTANICAL EVIDENCE

The archaeobotanical results are summarised in Table 3.2, with the full dataset in Appendix 1. The 17 samples produced a modest assemblage of charred plant remains, with 167 charred plant remains identified. The flots are small to moderate in size (c.250ml on average) comprising abundant modern roots and varying quantities of charcoal and charred plant remains. The density of charred plant remains is low, ranging from 0.3 to 2.5 items/L. The assemblage includes cereal grains, chaff and wild/weed taxa, alongside low numbers of millet grains, pulses and flax capsules. The level of preservation is generally poor and many of the cereal grains present could not be identified to species.

Crops

The cereal species identified include rye, free-threshing wheat and barley. The better preserved barley grains can be identified as hulled barley, with symmetric and asymmetric grains noted indicating the presence of 6-row hulled barley. Only a small number of indeterminate barley rachis fragments are present and consequently the presence of 2-row hulled barley cannot be excluded. Other chaff remains include one indeterminate free-threshing wheat rachis and several rye rachises. Some of the rye rachis segments are (sub-)basal. The assemblage is dominated by grains, whilst chaff and weeds are comparatively rare (Table 3.3).

A single millet grain recovered is probably foxtail millet. Lentil seeds are present in low numbers in three samples and one bitter vetch seed is present in sample 9. Flax is also recorded, with evidence comprising three capsule fragments in samples 1/5, 11 and 14. Theoretically, the flax capsule fragments could derive from a single plant, though this is unlikely since they were recovered from both Areas 1 and 3 in separate samples. Fruit/nut remains are very rare, comprising fig nutlets, a single mulberry fruitstone and a single pedicle which is probably from a grape.

Wild/weed taxa

A small assemblage of wild/weed taxa is present, with 49 remains identified, reflecting approximately 14 different taxa/types. All of the samples can be classified as 'mixed' and it is not possible associate specific weeds with crops (see Chapter 2, section 2.2.2). The remains are generally poorly preserved, making identification to species difficult. This includes *Asperula/Galium* sp., *Chenopodium* sp., *Chenopodium album*-type, *Medicago* sp., *Polygonum convolvulus,* indeterminate Polygonaceae*, Portulaca oleracea,* cf. *Reseda* sp., *Rumex* sp. and *Silene* sp. These are all annuals, and typically associated with arable and ruderal habitats. They all have early/intermediate flowering periods and could have been in seed when cereals were harvested (June/July).

3.2.1.3 OVERVIEW

Sample composition and formation

The low-densities of cereal grains, chaff and weeds within the occupation deposits of the two houses/rooms probably derive from the routine processing of cereals for consumption (discussed below). Much of this material is likely to have become charred in domestic hearths, subsequently becoming redeposited within the occupation layers. The generally poor level of preservation is also typical of material charred in hearths (Guarino and Sciarrillo 2004).

Crop-processing and arable weeds

The ratios of cereal grains to chaff and weed seeds suggests a (semi-) cleaned grain product, though the total number of remains is low (Table 3.3). Free-threshing cereal grains are typically stored in a semi-cleaned state and taken from storage and processed on a day-to-day basis for consumption (Hillman 1985). This semi-cleaned grain often contains cereal-sized weed seeds, small stones, occasional culm nodes and the basal parts of rachises. Small-seeded weeds and small rachis fragments may also be present depending on the thoroughness of fine sieving. Prior to consumption, additional fine sieving and hand sorting would be undertaken to remove these contaminants. These ‘cleanings’ are commonly discarded onto domestic fires and this seems the mostly likely route of preservation for the charred assemblage. Evidence for cereal processing is also provided by identification of a rotary quern in Area 3. Cereal grains could easily have become charred during processing, particularly if this was undertaken in proximity to domestic hearths (Hillman 1985; Alonso et al. 2014b) The chaff by-products from earlier processing stages could have been used as fuel source (van der Veen 1999). This may also account for the presence of flax capsules, which could have been deliberately burnt once the seeds had been extracted. Similarly, the other crops/crop items recorded including pulses and fruit remains could reflect material which has been deliberately discarded into hearths, or incidentally charred (i.e. below the base of the hearth, or close proximity to it).

The few remains of wild/weed taxa present possibly reflect arable weeds since they are likely to have been in seed when cereals were harvested (June/July). *Chenopodium* sp., *Polygonum convolvulus* and *Portulaca oleracea* commonly grow in ruderal habitats, preferring moister soils rich in nitrogen. These weeds are more commonly associated with spring-sown crops due to their long-flowering periods and preference for disturbed soils. Consequently, they are often associated with garden cultivation, though they can also grow in winter-sown cereals (Jones et al. 2000). However, any links between the wild/weed taxa present and cultivated cereal fields is tenuous since the occupation deposits sampled contain a mixture of material from several sources. Similarly, it has been demonstrated that fine-sieving can artificially skew the proportions of summer and winter annual species within an assemblage. In particular, summer annuals typically have smaller seeds than winter annuals and they are therefore likely to be overrepresented in fine sieving by-products (Jones 1992; Bogaard et al. 2005).

3.2.1.4 SUMMARY OF THE ARCHAEOBOTANICAL EVIDENCE

- The samples produced a moderately sized archaeobotanical assemblage, dating to the Islamic period (11th-12th century).

- The assemblage probably reflects material which was routinely charred by accident in domestic hearths during processing or food preparation. Crop-processing by-products may also have been deliberately discarded into hearths.

- The cereal species identified include free-threshing wheat, hulled barley and rye. The assemblage is generally poorly preserved. Barley and free-threshing wheat rachises could not be identified to species. The rarity of chaff and weed seeds, relative to grain, are indicative of a (semi-) cleaned grain product.

- Other crops identified include probable foxtail millet, pulses (bitter vetch, lentil) and flax. Unusually, the evidence for flax comprises capsule fragments. Remains of fruits/nuts are very rare and include fig, mulberry and probably grape.

- The small assemblage of wild/weed taxa includes arable and ruderal species, some of which are likely to derive from cultivated fields brought in with the (semi-) cleaned grains.

3.2.2 El Quemao, Sarrión (10th-12th centuries)

El Quemao is situated on a small area of elevated ground above dry-farmed cereal fields, c.4km north-west of the current town of Sarrión (Figure 3.5). The site is today covered in holm oak and low scrub. Within the wider region, it is situated in the south of the province of Teruel, close to the border with modern Castellón and Valencia. The site is a small, rural Islamic settlement covering an area of c.<2ha, with a cluster of 8/9 houses, each with several rooms and a central courtyard. To the west of the site, traces of terraces have been identified and it is possible that these are also Islamic in date. No irrigation features are clearly associated with the settlement. Evidence for earlier occupation in the Iberian-Roman period has also been identified, though this activity appears to be concentrated in a different area of the site, away from the Islamic settlement.

Between 2016 and 2018, small-scale excavations were undertaken at the site as part of the project *Husun y Qura: Estudio del poblamiento andalusí* (Villargordo Ros 2017, 2019). In the 2017 season, 4 trenches were excavated targeting different rooms/houses (Figure 3.6). In 3 of the trenches excavated, the only Islamic occupation deposits identified were thin clay floor surfaces which were constructed from (and situated directly above) the natural sub-soil. These contexts were considered unsuitable for sampling since they were essentially natural soils. Consequently, only samples in Trench 1 (House 2) were selected for analysis to prioritise contexts with good potential for the recovery of plant remains and to minimise sampling contexts with poor contextual integrity. The archaeological remains identified include mixed occupation deposits, ash-rich spreads of material and a large silo [17-18] in the corner of one of the rooms (Figures 3.7-3.8). This silo measured 1.7m in depth, with a maximum width of 1.3m (the opening at the top measured 0.9m). It was sealed beneath a layer of rubble and contained a series of distinct fills:

- (17-19): Mixed deposit consisting of rubble and general occupation debris.
- (17-20): Ash-rich deposit (17-20). This was also identified covering the floor surface of the surrounding room (17-10).
- (17-22): Collapse of the walls/edges of the silo. This context was not sampled.
- (17-23): Thick, ash-rich context (0.88m), containing abundant charcoal and finds.
- (17-24): Thin, ash-rich context (0.10m), containing abundant charcoal and very few finds.
- (17-25): Basal fill (0.25m), comprising of mixed deposit of pottery and charcoal.

Finds recovered from the silo [17-18] included abundant faunal remains and pottery, with sherd links between contexts. Other finds included an intricately carved bone mount for a box, dated to the 9th-10th century, and decorated with zoomorphic designs. A whole iron mattock/hoe (*azada*) was also recovered from the silo.

In the 2018 season, a single larger trench was excavated over one house (House 1A), revealing different rooms and a central patio/courtyard (Figure 3.9). The contexts/features types included the fill of a central drain within the courtyard, occupation/floor deposits, mixed refuse deposits and small ash-rich deposits.

Diagnostic pottery and other artefactual evidence place the occupation of the site between the 10th and 12th centuries, with more than one phase of occupation (Villargordo Ros 2018, 2019). As part of this PhD, two direct AMS ^{14}C dates were obtained (Table 3.4) to date the archaeobotanical assemblage within fill of silo [17-18] in Trench 1 and to date an ash-rich deposit, (18-11), containing abundant charred plant remains in Trench 5. In Trench 1, a free-threshing wheat grain from (17-23), a thick ash-rich deposit filling silo [17-18] returned a date of 890-1000 cal CE (SUERC-88605). In Trench 5, a hulled barley grain from (18-11) returned a date of 1010-1160 cal CE (SUERC-88606); this provides a date for one of the latest features in Trench 5.

3.2.2.1 SAMPLING

Overall, 21 samples were collected with a total sample volume of 644L (Table 3.5). For the 2017 season, 9 samples were collected, with a total sample volume of 479L. The fills of silo [17-18] were 100% sampled. A 25% sub-sample of the thick, ash-rich deposit (17-23) was processed due to the large size of this context. The ash-rich occupation deposit, (17-10), was also 100% sampled on-site and a 10% sub-sample was processed. For the 2018 season, most of the contexts suitable for sampling were small, and 100% of the excavated deposit was collected in all cases.

3.2.2.2 ARCHAEOBOTANICAL EVIDENCE

The archaeobotanical results are summarised in Table 3.6, with the full dataset in Appendix 2. The 21 samples analysed produced a large assemblage, with 4722 charred and 195 mineralised plant remains identified. The flots vary in size from very small (80ml) to very large (>1000ml), comprising varying quantities of charcoal and charred plant remains. Modern roots are common to very abundant in the flots, though modern wild/weed seeds are only present in trace quantities in some of the samples. In Trench 1, the flots are generally very large, containing abundant charcoal, particularly from contexts in silo [17-18], with sample 4 producing a flot 13,500ml in size. In comparison, the flots from Trench 5 are generally smaller and contain less charcoal, though charred plant remains are present in high densities in samples 10, 13, 14, 19, 20 and 23. Overall, the density of charred plant remains ranges widely from 0.2 to 48 items/L. Samples 4 and 10 produced the largest assemblages of charred plant remains. The level of preservation is variable, though it is typically poor.

The charred plant remains primarily comprise cereal grains, chaff, pulse seeds and wild/weed taxa, whilst other crop items are rare. The discussion below combines the archaeobotanical evidence from both trenches together, though reference is made to particular samples/trenches.

Crops

The cereal species identified primarily comprise free-threshing wheat and hulled barley, with less evidence for rye and emmer/einkorn wheat grain are only recorded in one sample. In general, the cereal grains are very poorly preserved and a high proportion (56%) of the grains are unidentifiable.

The free-threshing wheat grains are typically short and stubby in morphology (cf. Jacomet 2006). One grain in sample 4 has clear evidence for rodent gnaw marks. Diagnostic free-threshing wheat rachises are generally too poorly preserved to enable identification to species. Some of the better preserved examples can be identified as durum wheat, though one rachis in sample 10 may be from bread wheat. Considering the generally poor level of preservation, bread wheat cannot be excluded. Most of the barley grains are too poorly preserved to identify to species, though the better preserved grains are clearly hulled. Low numbers of both symmetric and asymmetric grains indicate that 6-row barley is present. Identifiable barley rachises are all from 6-row hulled barley, though the presence of 2-row hulled barley cannot be excluded. Rye grains are present in comparatively lower numbers in 15 samples. However, rye rachises are particularly common, including (sub-)basal segments, especially in samples 3, 10 and 11. Sample 11 produced two emmer/einkorn wheat grains and one indeterminate glume wheat spikelet fork. Overall, the cereal assemblage is dominated by grains, with only two samples (3, 11) containing comparatively high ratios of rachises, predominantly from rye (Figure 3.10).

Millet grains are generally present in low numbers, with the exception of samples 4 and 5. Most of the grains are broomcorn millet, with the presence of both hulled/unhulled and immature/mature grains noted. A large number of *Setaria* sp. grains are present in sample 4, however, these are probably from weed species, green/bristly foxtail millet (*Setaria* cf. *verticillata/viridis*) based on their slim morphology (Nesbitt and Summers 1988).

Ten samples produced low numbers of pulse seeds, with lentil, pea, red pea and bitter vetch recorded. An exception to this is sample 10 which produced a rich assemblage of pulses, comprising a total of 372 seeds (9 items/L). In general, the pulses are poorly preserved and a large proportion (28%) are indeterminate. In order of abundance, the species recorded include lentil, red pea, pea and bitter vetch. The pea seed fall into two types: Type A with a clearly spherical morphology and Type B with a cuboid-spherical morphology. This variability in pea morphology may reflect two different cultivars, different position of the peas within the pod or moisture content when charred. The red pea seeds are tentatively distinguished from grass pea based on their small size. It may be possible to identify some of the indeterminate pulse seeds with the use of a larger reference collection.

Flax is only recorded in sample 4 and represented by one seed and one capsule fragment. Sample 2 produced two probable mineralised gold-of-pleasure seeds. These seeds have lost their distinctive rugose surface pattern, though their overall morphology and large size (>3mm) is comparable to gold-of-pleasure.

Fruit/nut remains are typically present in low numbers and comprise fig, grape, mulberry and hackberry in order of abundance. Fig nutlets are present in 13 samples and mineralised fig nutlets are present in three samples. Sample 2 produced a fragment of a fig fruit, whilst sample 10 produced a small number of fig nutlets and large fragments of fig fruits including peduncles and fragments of fruits. Mulberry fruitstones are also recorded in sample 10 and 12. Evidence for other fruit/nut remains is slight, with small quantities of grape pips (whole and fragmented) and pedicles present in five samples. Low numbers of mineralised fig nutlets and grape pips are also recorded in the samples from silo [17-18].

One find of particular interest is a whole garlic clove in sample 10 (Figure 3.10).

Wild/weed taxa

In total, 1429 remains of wild/weed taxa have been identified, representing approximately 32 different taxa/types. In general, wild/weed taxa are present in low numbers, with the exception of samples 4 and 10. Poaceae spp. are the most common remains, with taxa identified including Apiaceae, *Asperula* sp., *Avena* sp., *Chenopodium* sp., *Chenopodium album*-type, indeterminate small-seeded Fabaceae, *Fumaria* sp., *Galium* sp., cf. *Glaucium corniculatum*, cf. *Lamiaceae*, *Lithospermum* sp., Medicago*/Meliotus* sp., *Malva* sp., Boraginaceae, *Papaver* sp., cf. *Plantago* sp., indeterminate Polygonaceae, *Polygonum convolvulus*, *Portulaca oleracea*, *Setaria* cf. *verticillata/viridis*, *Silene* sp. and *Vicia* sp..

Two samples, 4 and 10, produced comparatively rich assemblages in wild/weed taxa. In sample 4 from silo [17-18], the assemblage is dominated by *Chenopodium album*-type seeds and *Setaria* cf. *verticillata/viridis.* These are both ruderal species, with a preference for nitrogen-rich and slightly moister environments. An assemblage of mineralised wild/weed taxa was also recorded in samples 1 and 4 including *Agrostemma githago*, *Cirsium* sp., *Glaucium corniculatum*, *Papaver* sp., Poaceae spp. and *Silene* sp. In sample 10 from an ash-rich deposit, a diverse range of wild/weed taxa are present alongside abundant crop remains including *Chenopodium* sp., indeterminate small-seeded Fabaceae, *Galium* sp. cf. *Glaucium corniculatum*, *Lithospermum* sp., *Malva* sp., *Medicago* sp., *Papaver* sp., *Plantago* sp., small/large Poaceae spp., indeterminate Polygonaceae, *Setaria* sp. and *Silene* sp. In particular, *Galium* sp. seeds (probably *G. aparine*) are common (n=48) and species within this genus are scrambling plants commonly harvested alongside cereals or pulses (Hillman 1991).

The wild/weed taxa are all either winter or summer annuals[3], and they are typically associated with arable and ruderal habitats. They have an early-intermediate flowering onset period, with flowering durations ranging from short (1-3 months), medium (4-5 months) to long (>6 months). These wild/weed taxa could therefore have been in seed when cereals were harvested (June/July). One exception to this is *Setaria* cf. *verticillata/viridis* in sample 4 which flowers late in the season (July onwards).

3.2.2.3 STABLE CARBON ISOTOPE ANALYSIS

In total, 60 cereal grains (6-row hulled barley, free-threshing wheat, rye) and 10 pulse seeds (lentils) were selected for stable carbon isotope analysis. Samples dating to the 10th century were analysed from silo [17-18] in Trench 1, whilst samples dating to the 11th-12th century were analysed from an ash-rich deposit (18-11) in Trench 5. The results are analysed separately for each trench. Although a large number of cereal grains were recovered from the site, these were generally poorly preserved and unsuitable for stable isotope analysis. Mean $\Delta^{13}C$ values are presented in Table 3.7 and box plots of the results are presented in Figure 3.11. The results for each sample individually are presented in Appendix 3.

For silo [17-18] (contexts 17-23, 17-24), the mean $\Delta^{13}C$ values for 6-row hulled barley and free-threshing wheat are 17.0 ± 0.5‰ and 15.9 ± 0.6‰ respectively. Both of these results are consistent with rainfed cultivation and the small variation in $\Delta^{13}C$ values also suggests that the samples could potentially derive from a single harvest. The mean $\Delta^{13}C$ value for rye grains is 16.3 ± 1.0‰, falling within 'severe drought' range recorded by Kottmann et al. (2014).

For context (18-11), the mean $\Delta^{13}C$ values for 6-row hulled barley and free-threshing wheat are 17.7 ± 0.8‰ and 16.4 ± 0.8‰ respectively. These $\Delta^{13}C$ values are slightly higher than the samples from silo [17-18], though they are still consistent with rainfed cultivation. The small variation in $\Delta^{13}C$ also suggests that the crops were harvested from a single field. The mean $\Delta^{13}C$ value for lentils is 17.8 ± 0.8‰, falling above the 'well-watered' range defined by Wallace et al. (2013).

3.2.2.4 OVERVIEW

Sample composition and formation

[3] None of the taxa recorded can be clearly identified as perennials, though identifications to species would be necessary to exclude perennial species.

In Trench 1, the archaeobotanical assemblage in sample 3 from the ash-rich occupation layer (17-10) and samples 1, 2, 4 and 5 from the ash-rich fills of silo [17-18] could have formed through broadly similar processes. This inference is supported by their similar ash-rich nature and the presence of pottery sherd links between the contexts. These deposits are likely to include fuel waste, refuse, crop-processing debris and background settlement 'noise'. However, sample compositions differ between the contexts, suggesting that they probably include plant remains from different sources. In particular, the presence of mineralised remains of fruits (fig nutlets, grape pips), cereal grains and wild/weed taxa are indicative of midden-type deposits rich in organic waste (McCobb et al. 2003). An element of cess/latrine waste may also be present since grape pips and fig nutlets are consumed with the fruit, and the gold-of-pleasure seeds may also have been consumed (cf. Alonso 2005). The use of silos as rubbish pits and latrines once they had finished being used as grain stores is well-documented in medieval/Islamic sites (Malalana Ureña et al. 2013; van Staëvel et al. 2016; Alonso et al. 2014b, 2017). The preservation of cereal grains and probable arable weeds (see below) by mineralisation is more unusual, though this material potentially reflects crop-processing debris discarded alongside organic-rich refuse (Marshall et al. 2008; Fuller and Pelling 2018). The archaeobotanical assemblage from the silo can be contrasted with samples 7, 8 and 9 from nearby occupation deposits which contain very low densities of charred plant remains, probably reflecting background settlement 'noise'.

In Trench 5, different preservation pathways can be suggested for some of the samples. Here, several samples (13, 14, 19, 20, 23) from small ash-rich deposits contain high proportions of grain and few other remains. These samples could reflect accidentally spilled grain during food preparation. Sample 10 stands out as unusual since it contains abundant remains of cereal grains and pulse seeds, together with chaff, fig fruit fragments, a garlic clove and large assemblage of wild/weed taxa. This sample was collected from the corner of a room and it clearly contains a mixture of material from several sources. In comparison, samples 18, 21 and 22 collected from floor/occupation deposits contain few cereal grains and probably reflect a mixture of background settlement noise and accumulations of refuse.

Exceptions to this samples 11 and 12 (from the same context) which contain a high proportion of rye rachises (with rye making up 81% of the remains). This sample comes from an obviously mixed context containing pottery, ash, charcoal and faunal remains, and it can be contrasted against the grain-rich deposits outlined above. The high proportion of rye rachises may derive from an earlier crop-processing stage such as the by-product from coarse sieving. Interestingly, this sample also produced the only diagnostic remains of glume wheats, comprising two emmer/einkorn grains and an indeterminate spikelet fork. Clearly, a different taphonomic origin accounts for the range of plant remains within these two samples.

Crop-processing and arable weeds

In general, the low ratios of rachises to grain and weed seeds to grain suggests that most of the samples in both trenches contain (semi-)cleaned grain products (Table 3.8; Figure 3.12; van der Veen 2007). Whilst chaff is likely to be partly underrepresented due to a preservation bias (Boardman and Jones 1990), weeds are also generally rare and it is thought these smaller, denser remains should still be represented in samples with poor preservation (Jones 1987). This suggests that most of the samples are genuinely grain-rich. The near-absence or rarity of crop-processing by-products from the earlier stages of threshing, winnowing, coarse sieving is unsurprising since these activities would typically be undertaken outside settlements due to the dust created (Hillman 1984:8, 1985). Additional coarse sieving, fine sieving and hand-cleaning to remove stray rachises, culm nodes and other contaminants could then have been undertaken within the settlement on a routine basis when required (Hillman 1985; Fuller et al. 2014). One exception to this pattern is sample 10 which produced a relatively large assemblage of culm nodes and rachis segments from rye, free-threshing wheat and barley. This material probably derives from an earlier crop-processing stage, suggesting that some unprocessed cereals were also brought into the settlement.

It is possible that some cereals were stored in the ear and the 12th century agronomist Ibn al-'Awwām mentions the storage of cereal ears in silos (Malalana Ureña et al. 2013). This is also supported by ethnographic data from Morocco and desiccated archaeological finds (12th-14th century) of cereal ears from Valencia (Peña-Chocarro et al. 2015). This could be a factor in explaining the occurrence of rachises at the site, particularly the case of rye rachises which are comparatively frequent. The relatively common occurrence of rye rachises could also reflect the use of rye straw as a construction or binding material (e.g. thatching, weaving, binding cereal sheathes or hay) (Halstead 2014:78, 96, 139). However, it is unclear whether rye rachises have a higher potential of surviving charring due to their small size and dense form, compared to either barley or free-threshing wheat rachises

In Trench 1, sample 4 from silo [17-18] produced a large assemblage of cereal grains, broomcorn millet and wild/weed taxa. Due to the mixture of different crops present, the wild/weed taxa present cannot be directly associated with a specific crop. However, the large number of *Setaria* cf. *verticillata/viridis* caryopses identified may be a weed of broomcorn millet since both these species ripen late in the season (July), i.e. after cereals are harvested. *S. verticillata* and *S. viridis* cannot be separated based on grain morphology (Nesbitt and Summers 1988). They both have a preference/tolerance for nitrogen-rich soils, though *S. verticillata* typically grows in wetter conditions. Other nitrophilous species with a preference for slightly moister environments are also present including *Chenopodium album*-type, *Polygonum convolvulus*, *Malva* sp. and *Portulaca oleracea*. These species have intermediate/long flowering periods, a functional attribute typical of species growing in disturbed habitats such as hoe cultivated fields (Jones et al. 2000).

The small assemblage of mineralised wild/weed taxa in silo [17-18], samples 1 and 4, are probably arable weeds. This includes *Agrostemma githago*, *Cirsium* sp., *Glaucium corniculatum*, *Papaver* sp., Poaceae spp. and *Silene* sp. With the exception of *Silene* sp. and Poaceae spp., these taxa were not recorded in the charred assemblage. *Agrostemma githago* is a character species of the phytosociological Secalinetea class associated with (rainfed) winter cereal fields (Braun-Blanquet and de Bolós 1957). *Glaucium corniculatum* has a short flowering duration (3 months) and finishes flowering early in the season (June). Consequently, it is a common weed in rainfed cereals (Braun-Blanquet and de Bolós 1957; Guillerm and Maillet 1982; Cirujeda et al. 2011).

In Trench 5, samples 13, 14, 19, 20 and 23 are particularly grain-rich and contain few 'contaminants' of other crops (e.g. pulses, fig seeds). These samples all come from the central courtyard of the structure and they could reflect accidentally spilled grain during the preparation of foodstuffs, particularly during boiling or roasting (Hillman 1985; Alonso et al. 2014b). Although these samples come from different contexts, it is possible that they derive from the same processes due to the similarity of their compositions and their close proximity to one another.

A mixture of different cereal species is present, though in some cases near-pure assemblage of a single cereal species or maslins of free-threshing wheat and hulled barley may be present. For instance, barley forms 92% of the identifiable grain assemblage in sample 19 and 72% in sample 20. In comparison, samples 13, 14 and 23 contain a mixture of free-threshing wheat and hulled barley, together with some rye. All of these samples contain probable arable weeds, though only low numbers of poorly preserved remains are present. The taxa recorded include *Asperula* sp., *Chenopodium* sp., *Galium* sp. *Medicago* sp., Poaceae spp., *Silene* sp., *Vicia* sp.. These weeds are small-seeded (assuming they are separated from flower heads/pods) and they could reflect the by-product of additional fine-sieving undertaken prior to consumption (Jones 1987; van der Veen 2007).

3.2.2.5 SUMMARY OF THE ARCHAEOBOTANICAL AND CROP STABLE CARBON ISOTOPE EVIDENCE

- The samples from the two trenches produced a large archaeobotanical assemblage dating to the Islamic period (10th-12th centuries).

- The assemblage includes material from several different sources, including domestic refuse, crop-processing debris, background settlement 'noise' and possibly, in some cases, an element of cess/latrine waste. Most of the samples contain a mixture of material, though a series of grain-rich samples in Trench 5 are likely to reflect accidentally charred grain during processing or food preparation.

- The assemblage is dominated by cereals. Free-threshing wheat, hulled barley and rye are the most frequent species. The identifiable free-threshing wheat rachises are from durum wheat, with one possible bread wheat rachis. The barley grains are generally indeterminate, though sufficient numbers of well-preserved grains are present to be identified as hulled barley, with both symmetric and asymmetric grains present indicating 6-row hulled barley. The presence of 2-row hulled barley cannot, however, be excluded. Rye also occurs throughout the samples. There is sparse evidence for other cereal species, with two indeterminate glume wheat grains and one indeterminate spikelet fork in one sample. The samples are typically grain-rich, probably indicating that (semi-) cleaned grain was brought into the settlement and charred accidentally during food processing/preparation.

- Other crops identified include broomcorn millet, flax, gold-of-pleasure, and pulses (red pea, pea, lentil, bitter vetch). One unusual find is a whole garlic clove. Fruits/nuts identified comprise grape, mulberry and fig, with near whole fig fruits present in one sample. Low numbers of mineralised remains also include grape and fig.

- A large assemblage of wild/weed taxa is present, though nearly all the samples are classified as 'mixed' and it is not possible to directly associate specific weeds with crops. Despite this, the wild/weed taxa are probably from cultivated fields/gardens since the assemblage is dominated by arable and ruderal species.

- The crop stable carbon isotope results for rye, free-threshing wheat and hulled barley are indicative of rainfed cultivation. All of the cereal grain $\Delta^{13}C$ values fall below the expected ranges for well-watered (i.e. irrigated) crops. Rye may also have been cultivated under similar conditions. In comparison, the high $\Delta^{13}C$ values for lentils probably reflect irrigation.

3.3 Discussion

This section brings the archaeobotanical evidence together from the two sites examined, discussing it within a local and regional context. The primary focus is on El Quemao since a significantly larger archaeobotanical assemblage was recovered from this site. No previous archaeobotanical research has been undertaken on any Roman, early medieval, Islamic or later medieval sites within the region and only a handful of studies (primarily unpublished) exist for the neighbouring region of Valencia (Peña-Chocarro et al. 2019; see Chapter 5). Similarly, there is also a dearth of documentary evidence for the Islamic period, with the existing sources primarily concerned with irrigated areas and urban centres in the north towards Zaragoza and in the east towards Valencia (Ortega Ortega 2010). Only one source of the 11th/12th century gives a generalised picture of agriculture, referring to the territories of the Banu Razin around Albarracín as the 'most fertile' in the Upper March and noting the 'abundance' and 'variety of crops' grown there (Bosch Vilá 1959: 54).

The archaeobotanical evidence analysed here provides the first record of the range of crops cultivated during the Islamic period in this area, as well as providing insights into the crop husbandry practices. At both sites a similar range of crops are present, with cereals dominating the assemblages. The species recorded include free-threshing wheat, rye and hulled barley, probably the 6-row type. In the case of El Quemao, durum wheat has been positively identified. There is sparse evidence for glume wheats with emmer/einkorn recorded in one sample at El Quemao and these remains could be a crop contaminant (Jones and Halstead 1995). No definitive evidence for the cultivation of oats is recorded at either site and the low numbers of grains identified are likely to be weeds. It is possible that oats are missing from the archaeobotanical record if most of the crops present were intended human consumption, since oats have been commonly favoured as a source of fodder (Jones 1998). Wheat, barley, rye and oats are all referred to in later medieval documentary sources for the region, and oats probably became a more important crop after the Islamic period (e.g. Muñoz Garrido 1999; Abad Asensio 2006; Navarro Espinach 2017).

The large silo identified at El Quemao is probably related to the storage of cereal grains, only later becoming filled with refuse, as has been documented in other Islamic sites (cf. Malalana Ureña et al. 2013; Alonso et al. 2017). Above ground storage features may also have been present, though these are less likely to be identified archaeologically (Peña-Chocarro et al. 2015). The silo was situated in the corner of a room within the building, probably reflecting private storage at the household level. The use of silos to store 'normal surplus' (typical overproduction of crop requirements) was commonplace in the recent past throughout the Mediterranean, mitigating against the risk of shortages since crops could be stored for several years (Halstead 1989; Forbes and Foxhall 1995; Forbes 2017). This practice is also indicated in documentary sources for the Islamic period, where silos are described for this same purpose and were considered an effective method for storing cereals, as well as nuts (hazel nut, walnut, almond), and even dried fruits (Malalana Ureña et al. 2013:342-343). In particular, hulled barley and durum wheat which have low water contents are well-suited to long-term storage. Silos were typically lined and often packed with straw, with ethnographic data indicating the use of einkorn for this purpose (Halstead 2014:157-159; Peña-Chocarro et al. 2015). Chaff, dung, clay and ash (a natural insecticide) may have been combined to form a lining and to seal the silo (Malalana Ureña et al. 2013; cf. Hakbijl 2002). The evidence for rodent gnaw marks on one free-threshing wheat grain highlights the potential vulnerability of stored crops to pest damage (cf. Halstead 2014:161).

The crop stable isotope evidence from El Quemao clearly indicates that free-threshing wheat and hulled barley were cultivated under rainfed conditions. Comparative evidence from the weed assemblage cannot be used to directly infer cereal cultivation practices due to the mixed nature of the assemblage, though some weeds present are likely to be associated with cereals. Pure crop samples, containing few contaminants, would be required to investigate aspects such as sowing time, harvesting method or the scale and intensity of cultivation (Jones et al. 2010). The evidence for rainfed cultivation is consistent with the archaeological interpretation of the site. Large-scale irrigation would not have been possible due to the nature of the topography and the lack of suitable water-sources in the vicinity of the site. Survey of the areas surrounding the site has not identified any evidence for irrigation channels, though this does not exclude the possibility that small cultivated areas received some irrigation (see below) through methods such as rainwater capture, which have been documented at other sites (cf. Chapman 1978; Jiménez Castillo and Simón García 2018).

The evidence from El Quemao suggests hulled barley and free-threshing wheat were cultivated under similar conditions, and it is possible that they were cultivated together as a maslin (cf. Jones and Halstead 1995). Possible evidence for this also comes from the grain-rich samples in Trench 5 which contain mixtures of hulled barley and free-threshing wheat, together with some rye. The identification of maslins is challenging from an archaeobotanical perspective since monocrops were rarely pure, often containing admixtures of other cereals and pulses as contaminants, and crops may have been mixed together post-harvest or through charring and redeposition (Jones and Halstead 1995). However, maslins of wheat/barley, wheat/rye and cereals/pulses have traditionally been cultivated across the Mediterranean as a means of risk management (Hillman 1978; Jones and Halstead 1995; Forbes 1998). By cultivating a maslin, it is possible to take advantage of good years with sufficient rainfall which favours less drought-tolerant crops such as free-threshing wheats, whilst hulled barley can cope well with unfavourable growing conditions. The omnipresent risk of drought is highlighted in a *fatwa* (legal document) from 1084 in Zaragoza, which highlights that rent must still be payed on a wheat crop if it fails for any other reason than drought (Lagardère 1995:no.209). Similarly, it is known that grain had to be imported into al-Andalus in the 9th century (Constable 1996:134, 141-2) and severe droughts are recorded in chronicles between the 8th and 11th centuries (Domínguez-Castro et al. 2014).

Documentary sources indicate that maslins were cultivated in the later medieval period in the north-east of Iberia and southern France (Ainaga Andrés 1987:n.73; Forey 1988; Comet 1992:249; Alonso 2000; Latorre Ciria 2007). Contemporary Islamic sources of the 11th and 12th centuries describe the best bread as that made of wheat, they also mention how bread could be made of any mix of several cereal types, dried legumes or even vegetables, especially during times of shortage (Bolens 1980; García Sánchez 1983). In other cases, bread could be made from a mixture of wheat, barley and rye, as well as millets (Bolens 1980; García Sánchez 1983; García Marsilla 2013).

Other cereal crops recorded include millets, comprising a single grain of probable foxtail millet at Cabezo de la Cisterna and a large number of broomcorn millet grains at El Quemao. Though millets are a drought adapted crop, they may have required some supplemental irrigation since they grow during the dry summer period (cf. Miller et al. 2016). There is no evidence for sorghum at either site which is surprising, particularly in the case of El Quemao given the strong documentary evidence for its cultivation in areas around Valencia during the Islamic and later medieval period (Watson 1983, 1995; Guichard 2001). Similarly, archaeobotanical evidence for sorghum has also been identified in the later medieval settlement at Benialí, Valencia (Butzer et al. 1985b), though there is currently no other archaeobotanical evidence for sorghum in the Iberian Peninsula during the Islamic period (Peña-Chocarro et al. 2019; see Chapter 5).

Pulses were cultivated at both sites, with a greater diversity of species recorded at El Quemao which includes lentil, pea, grass pea and bitter vetch. Though grass pea may be a weed rather than a cultivated crop, it has traditionally been used as a source of both food and, in particular, fodder (Peña-Chocarro and Zapata Peña 1999; cf. Halstead and Jones 1989; Jones and Halstead 1995; Valamoti et al. 2011). Bitter vetch may also have been cultivated as fodder, though the small number of these remains could also represent contaminants of other crops (Jones and Halstead 1995). In comparison, lentil and pea have traditionally been favoured as a food crop, though the boundary between food and fodder crops is not always clear (Jones 1998; Halstead 2014:133-134). The predominance of lentil at El Quemao may reflect a preservation bias since the small seeds have a higher probability of surviving than other pulses when charred (Cappers and Neef 2012). Despite this, it is clear that a range of pulses were cultivated, and this would have mitigated against the risk of crop failure (Marston 2012). Peas and lentils have been considered sensitive to water shortages in the Mediterranean (more so than grass pea or bitter vetch), and often benefit from irrigation (Farah et al. 1988; Oweis et al. 2004; Kreuz and Marinova 2017). This inference is supported by the stable isotope evidence which suggests that the lentils at El Quemao were irrigated.

Flax is recorded in small quantities at both sites, with low numbers of capsule fragments at Cabezo de la Cisterna and one seed and capsule fragment at El Quemao. The evidence for capsule fragments is unusual since these remains are generally less frequently recovered than the seeds, presumably because they were discarded following processing and due to a preservation bias during charring (cf. Valamoti 2011; Orendi in press). The presence of capsules may be an indication of local cultivation. At both sites, flax could have been cultivated in rainfed areas, although the crop can benefit from supplemental irrigation or cultivation in naturally wetter soils, producing longer stems better suited to fibre production (Castro et al. 1999; Lloveras et al. 2006; Halstead 2014:230-231). It is, however, possible that these crops were acquired via trade. Evidence for gold-of-pleasure is also recorded at El Quemao and this is commonly thought to be a weed of flax crops (Lataowa 1998; Alonso 2005). However, the gold-of-pleasure seeds are mineralised and they occur alongside grape pips and fig nutlets suggesting that the crop was consumed. Alonso et al. (2014a) have also recorded mineralised gold-of-pleasure seeds at Islamic sites.

Fruit remains are generally present in low quantities at both sites with evidence for mulberry, fig and grape[4]. Hackberry was also recorded at El Quemao, in both mineralised and charred states of preservation. The relatively limited evidence for fruits and the low species diversity is likely to reflect the relatively harsh climate which is unsuited to the large-scale cultivation of these crops, although trade might have helped the supply. Dried figs, for example, were widely traded

[4] Grape is only represented at Cabezo de la Cisterna by a probable grape pedicle.

throughout al-Andalus (Constable 1996:220-221). Similarly, dried raisins were stored in ash and widely exported (Lapeyre and Carande 1959). In the modern landscape, fruits are primarily cultivated in the irrigated areas surrounding towns (*huertas*), or in smaller market-gardens (*huertos*) such as those in the nearby village of Sarrión at El Quemao. Similarly, documentary evidence generated after the Christian conquest of the Valencia region indicates the cultivation of a diverse range of fruits and vegetables, especially in irrigated *huertas* (e.g. Butzer et al. 1985b; Guichard 2001; Saura Gargallo 2015). As noted above, there is evidence to suggest that a small irrigated area probably existed at El Quemao, and this could potentially have supported the cultivation of some fruit species, pulses (see above) and millets. The evidence for garlic is also indicative of a small irrigated garden. Though the weed assemblage cannot be linked to specific crops, summer annual species typical of disturbed habitats such as hoe cultivated fields or gardens are common (Jones et al. 2000). It is interesting to note that a mattock/hoe was recovered from the site and these tools are traditionally used to cultivate soils and to weed in between crops.

Taken together, the evidence from both sites indicates that crop cultivation focused primarily on cereals (hulled barley, free-threshing wheat, rye), followed by pulses (lentil, bitter vetch, grass pea, pea). Millets (broomcorn millet) are only recorded in substantial quantities at El Quemao. Evidence for other crops is comparatively slight though it also includes fruits (grape, fig) and flax, with gold-of-pleasure also recorded at El Quemao. Rainfed areas were used for the cultivation of cereals at El Quemao, though there are several indications that a small irrigated area also existed at the site. The evidence from Cabezo de la Cisterna was generally poorly preserved, though a similar pattern of crop husbandry is likely to have existed there also.

4 Huecha Valley, Zaragoza, case-study area (early medieval, Islamic and later medieval sites, 6th-15th centuries)

This chapter presents the archaeobotanical and crop isotope evidence for the sites examined in the Huecha Valley, Zaragoza (Figure 4.1). The sites date between the early medieval (6th-early 8th centuries), Islamic (10th-early 12th centuries) and later medieval (Christian) periods (12th-15th centuries), with the aim of establishing a trajectory of change in a single landscape context. The research undertaken is linked to a larger ongoing project in the Huecha Valley, the *Moncayo Archaeological Survey* (MAS) which is investigating population, economic and environmental change in the Huecha Valley using systematic field survey, excavation and geo-archaeological research in prehistoric and historic periods (Wilkinson et al. 2005; Gerrard and Gutiérrez 2012, 2020). To date, some of the results of the MAS have already been published and these are cited in the sections below. However, as the project is ongoing, the results from the field surveys and the small number of excavations undertaken remain to be examined in detail. There is a significant disparity in the information available, with little known for the early medieval and Islamic periods, whereas significantly more information is available for the later medieval period due to documentary sources. The results presented here are the first archaeobotanical studies to be undertaken on medieval sites in the study area, and amongst the only to be undertaken in Aragón[5]. The only previous archaeobotanical research has examined evidence from prehistoric settlements (Wetterstrom 1994; Alcolea et al. 2018).

4.1 Regional setting

4.1.1 Present-day climate and topography

The Huecha Valley runs for c.51km from the Sierra de Moncayo in the south to the River Ebro in the north. The study area examined here is located to the west of Zaragoza province, encompassing the districts (*comarcas*) of Campo de Borja and Tarazona y el Moncayo. The most important urban centres within the region are Borja and Tarazona. Present-day settlements are primarily situated between c.300 and 600m (a.s.l.) in areas close to the River Huecha. The land

[5] Only one archaeobotanical study has been undertaken on an Islamic site in the north of Aragon (Ros et al. in press).

rises steeply as it approaches the Sierra de Moncayo, where it reaches 2314m (a.s.l.) (Figures 4.2-4.3).

The geology of the valley is primarily composed of Quaternary river terrace deposits and Tertiary sedimentary geology (clays, marls). Irrigated agriculture is concentrated within the Quaternary river terrace deposits, whilst dry cereal cultivation and rough pasture predominates in areas of Tertiary sedimentary geology. Beyond the cultivated areas are the badlands, severely eroded areas characterised by low scrubland and steppic grasslands. The natural vegetation primarily comprises shrub-land (e.g. *Cistus* sp., *Rosmarinus* sp., *Thymus* sp.) and grasses at lower levels typical of Mediterranean habitats (sensu Blondel et al. 2010:123-124). Areas above >700m are characterised by typical Meso-Mediterranean woodland species, holm oak, kermes oak (*Quercus ilex, Q. coccifera*), whilst Supra-/Montane-Mediterranean species, pines, beach, (e.g. *Pinus* spp., *Fagus sylvatica*) are present at higher altitudes (>1000m) (sensu Blondel et al. 2010:120).

Lowland areas of the valley are characterised by a cold semi-arid climate (Köppen–Geiger zone BSk), whilst areas of higher altitude towards the Sierra de Moncayo are characterised by a temperate oceanic climate (Köppen–Geiger zone Cfb). Mean annual rainfall for Borja is 417mm, with the majority of rain falling in spring and autumn. However, on an annual basis the quantity of rainfall can be erratic, with severe storms/flash floods between June and September, whilst droughts are not uncommon (Iberian Climate Atlas 2010; AEMET 2019). These severe weather events can be very damaging, causing crop failures (García Manrique 1960). There is considerable variation in mean annual rainfall between different areas of the valley; closer to the Sierra de Moncayo rainfall can exceed >600mm per year, whilst further downstream rainfall can be less <400mm per year. Despite this, rainfall is typically sufficient for rainfed cereal cultivation. The average annual temperature is 13-14^{o}C (January 4-6^{o}C; July 22-24^{o}C). Temperatures can reach 40^{o}C In July and -10^{o}C in December.

Agriculture in the region today comprises a diverse range of crops including cereals, fruit trees (primarily olives and almonds) and vineyards. In the recent past, a rotational system of hemp, flax, wheat and barley was widely cultivated. Irrigation in the region is still centred around a traditional system of *acequias* (gravity-flow irrigation channels) which distribute water across lower areas across the valley, irrigating several hundred hectares of land (Gerrard 2011). Irrigation was traditionally divided between three areas until the mid-19th century (García Manrique 1960:63):

- *Huertos*: intensively cultivated market-gardens.

- *Huerta*: an irrigated area traditionally used for the cultivation of cereals, flax and hemp.
- *Regadío eventual*, *orrillada* or *orillo*: areas of poorer soil, on the periphery of *la huerta*, occasionally receiving irrigation. These areas are primarily used for the cultivation of olives and vineyards today.
- *Secano* (or dry land) lies beyond this, an area reserved for rainfed cereal cultivation and the *bajo monte* (rough pasture).

4.1.2 Historical and archaeological context

4.1.2.1 EARLY MEDIEVAL PERIOD (5TH-EARLY 8TH CENTURIES)

The early medieval period is still poorly documented in the Huecha Valley. Whereas Roman settlements are densely distributed throughout the area, early medieval settlements are rare (Corral Lafuente 1992). Currently, the only substantial evidence for occupation in the early medieval period within the Huecha Valley is at Bureta, where small-scale excavation has pointed towards multiple phases of occupation in the 6^{th} to early 8^{th} centuries (Gutiérrez and Gerrard 2019), although stray finds hint at the existence of other settlements in the region (e.g. Paz 2004; García and Bonilla 2010:278; Aguilera 2014). Overall, the available evidence suggests that there was probably a significant reorganisation in rural settlement patterns from the late Roman to early medieval period in the Huecha Valley, echoing patterns seen elsewhere in Iberia (cf. Collins 2004: 197-222, 2014:12-13; Diarte-Blasco 2018:150-156). Bureta is therefore an important site for understanding this period, particularly when set against the comparative rarity of early medieval settlements across the wider Ebro Valley (Laliena Corbera 2010; Picazo Millán et al. 2016).

4.1.2.2 ISLAMIC PERIOD (8TH-EARLY 12TH CENTURY)

Very little is known about the nature of early Islamic settlement in the centuries following the conquest; documentary sources are almost non-existent for this period (Viguera Molíns 1995; Catlos 2002). The main urban centre was Borja, which has been identified as a *hisn* (fortified site) under the control of the Banū Qasī, a powerful *muwallad* family (converted Muslim) based in the city of Tudela (Lorenzo Jiménez 2007). The Banū Qasī controlled sizeable territories across the Ebro Valley between the 8^{th} and 9^{th} centuries and they were the dominant political force in the region (Kennedy 1996:54-59). By the 10th-11th centuries, the power of the Banū Qasī had declined and their territories were taken over by Arab families; first Tujībids and then later the Banū Hūd who came to rule the powerful Taifa state of Zaragoza (Kennedy 1996: 80-81, 136-137).

Current evidence suggests the Islamic settlements are distributed throughout lowland areas along the natural terraces which form the banks of the River Huecha (Wilkinson et al. 2005). In many cases, settlements appear to be located beneath modern villages/towns. A well-studied example of is at Ambel where the 11th century settlement comprised a small, three-storey fortified tower associated with silos and a walled enclosure, a mosque and nucleated settlement (Gerrard 1999; Blanco Morte 2007). Similarly, excavations at La Mora Encantada, near Bulbuente, identified a 10th-12th century settlement with evidence for a fortified structure/wall and silos, whilst a geophysical survey has also identified probable houses (Gerrard and Gutiérrez 2018b). Other evidence for Islamic settlements comes from documentary sources generated after the Christian conquests (12^{th}-13^{th} centuries) which contain common references to *almunias* (privately owned farmsteads/estates) (Teixeira 1993). However, this may be misleading since the term *almunia* could have been applied retrospectively to range of different settlement types (Laliena Corbera 2010; Ortega Ortega 2010). At present it is not possible to establish a detailed picture of settlement patterns in the Islamic period; however, it would appear that the generalised model suggested for al-Andalus of a *hisn* surrounded by a dispersed network of *alquerías* (hamlets/farmsteads) has no validity here (cf. Eiroa Rodríguez 2012).

In other areas of al-Andalus (such as Granada), it has been demonstrated that rural Islamic settlements were commonly associated with small irrigated areas (Martín Civantos 2018). Within the Huecha Valley, it is known that the present-day irrigation system was expanded and modified throughout the later medieval period, however, the origins of the system are more difficult to establish (Gerrard 2011). A key source of dating evidence for the irrigation systems comes from mid-late 12^{th} century documentary sources relating to a major Cistercian monastery at Veruela (Cabanes Pecourt 1987; Teixeira 1995; Lerín de Pablo 1999; Rodríguez Lajusticia 2010). These sources provide a *terminus ante quem*, confirming that some elements of the irrigation system already existed in the Islamic period. Similarly, it has been noted that the terminology used to distribute and allocate water from the *acequias* in the late 12th century was inherited from an earlier Islamic system (Arié 1982: 225; Glick and Teixeira 2002). Despite this, the full extent of the irrigation system in the Islamic period cannot yet be mapped, nor is it clear how much it overlaps, if at all, with earlier Roman systems (Gerrard 2011; Rodríguez Lajusticia 2014).

4.1.2.3 CHRISTIAN CONQUEST AND REPOPULATION (12TH CENTURY)

The Christian conquest of the Huecha Valley can be dated to the early 12th century, with the capture of Tarazona in 1119 and Borja in 1124 (or 1122), following a negotiated surrender (Stalls 1995:41-43). It is around this time that the first references to nearby settlements appear in documentary sources, which survive better than for earlier periods (e.g. Ambel: Gerrard and Gutiérrez 2003a:48). Within the wider region, there is debate over whether the Christian conquests led to the large-scale emigration of Muslims, or alternatively whether the majority of Muslim populations remained (Stalls 1995:297-301; Laliena Corbera 1998, 2005, 2007; Catlos 2004:95-100). In the Huecha Valley, Christians established themselves in frontier towns and strategic settlements such as Tarazona, Borja and Los Fayos, however, the local Muslim population appears to have largely remained in place, especially in irrigated valleys such as Grisel, Trasmoz, Bulbuente or Ambel (García Manrique 1960: 220). Muslims retained a degree of religious, political and economic freedom in return for paying tribute/tax (Corral Lafuente 1999; Catlos 2004: 96-97; Laliena Corbera 2005: 128-129).

Following the military campaigns, there followed a period of consolidation and repopulation, with large accessions of land and properties granted to trusted lords, monastic orders and the Military Orders (Forey 1992; Fernández Conde 2005). This was an important aspect of the colonisation process, with these powerful new landowners maintaining stability, order and control in this 'frontier' zone. Within the Huecha Valley, land and properties were acquired by the Hospitallers at Añón in 1140 and the Templars at Ambel in 1151 (Gerrard and Gutiérrez 2003a), whilst the Cistercians constructed a major monastery at Veruela beginning in 1147 (Vispe Martínez 1984). The arrival of the Cistercians and the Military Orders had direct social, economic, political and ideological impacts on the region, reflected in the introduction of a feudal regime, changes to settlements and a reorganisation of agricultural spaces (Catlos 2004:100, 2014:423). Amongst all this, Muslims continued to make up a significant proportion of the population and they were a key component of the agricultural system throughout this period until their expulsion in the early 17th century (García Manrique 1960: 219-228; Gerrard 1999; cf. Catlos 2004).

4.1.2.4 LATER MEDIEVAL PERIOD (12TH-15TH CENTURIES)

The degree of continuity and change in settlement patterns between the Islamic and later medieval period after the so-called 'reconquest' remains to be examined in detail. Whilst there is some evidence for the creation of new settlements, in many cases pre-existing settlements probably continued to be occupied following the Christian conquests (Teixeira 1995; Gerrard 1999) and some Islamic settlements were also abandoned (such as La Mora Encantada, see above), potentially with a shift towards nucleated communities (Gerrard 1999:147; cf. Laliena Corbera 2010:39-40).

Overall, the area had a relatively low population density through the later medieval period and the current evidence suggests that existing settlements were adapted. For example, at Ambel, the c.12th century the settlement underwent significant reorganisation (probably overseen by the Templars), with the construction of a *morería* (a separate new Muslim quarter), a church and the creation of a preceptory (Gerrard 1999). At Magallón, a similar reorganisation took place, with the creation of both a Muslim quarter and a *judería* (Jewish quarter) (Teixeira 1993). This segregation within towns also extended to agricultural areas (García Manrique 1960; Motis 1985; 1988; Assis 1997; Gerrard 1999). The new seigneurial centres represent an important change; they served as both as administrative units within the feudal regime and visible symbols of Christian authority (cf. Glick 2005:158-159).

It has been widely highlighted that one of the most significant changes which took place following the Christian conquests was the introduction of a feudal regime. In essence, this involved a shift from a 'tax-based' to a 'land-based' or 'rent-based' system where seigneurial lords extract revenues, primarily from agriculture (Glick 2005; cf. Wickham 1984, 2005:58). Whilst the ideal-type dichotomy between these two contrasting modes of production has been downplayed in recent years (e.g. Wickham 2008), the arrival of powerful new landholders, such as private landowners, the Cistercians and the Military Orders, did have a significant impact on the organisation of rural landscapes (cf. Pluscowksi et al. 2011).

Already by the late 12th to 13th centuries, the Cistercians and the Military Orders had begun to reorganise agricultural spaces to reflect their own requirements. Of particular importance was irrigation; higher rents could be charged from irrigated land (due to higher yields) making it a key source of income (Forey 1987:128-129). Similarly, an expansion in the area of irrigated land could have enhanced cereal yields (cf. Carranza Alcalde 2009), and it may also have been linked been to a shift in the crops cultivated. A wide range of documentary sources provide evidence for the modification and expansion of the pre-existing irrigation system, though it is difficult to establish the full extent of the irrigated area for earlier periods (Teixeira 1995; Gerrard 2011). The Cistercians played a central role in the reorganisation of irrigation systems, seeking to support a network of settlements and agricultural estates under their control (Rodríguez Lajusticia 2008; Gerrard 2011). Given the limited access to water in the area, this was also a priority for the Hospitallers at Añón and the Templars at Ambel; consequently, there were extensive disputes over irrigation rights between these major landholders throughout the later medieval period (Gerrard and Gutiérrez 2003b:87-88; Gerrard 2011; Rodríguez Lajusticia 2015). A considerable body of documentary evidence exists concerning the administration and allocation of water rights (Gerrard 2011).

Inseparable from the irrigation systems were mills and here seigneurial landholders held a monopoly over mill construction and use (e.g. Gerrard and Gutiérrez 2003b: 49; Forey 1987). The earliest identified mill belonged to the Templars at Ambel, dating to 1192; other mills have also been identified throughout the Huecha Valley (Gerrard 2011). Mills have often been considered as a defining element of the shift to a feudal regime in the later medieval period (Glick 2006). It is generally thought that change in the role and importance of mills accompanied an expansion in cereal cultivation (e.g. Stalls 1995:216-220; Laliena 1998; Glick 2005:91-94; Kirchner 2011, 2018, 2019; Kirchner et al. 2014). This may have involved a process of extensification, whereby the dry-cultivation of cereals expanded, though documentary sources also indicate that cereals were cultivated in irrigated areas (Gerrard 2011).

An expansion in vineyards and olive groves can be identified from the 12th-13th century onwards (e.g. Gerrard and Gutiérrez 2003b; Rodríguez Lajusticia 2010). Other important crops which commonly appear within the documentary evidence are flax and hemp, both cultivated for fibre (Ainaga Andrés 1987; Gerrard and Gutiérrez 2003b; Rodríguez Lajusticia 2014). Beyond cultivated areas, there may also have been a shift in animal husbandry practices, perhaps linked to transhumance. Rights to pasture feature in 12th-13th century *cartas pueblas* (settlement charters) as well as later documentary evidence (Cabanes Pecourt 1984; Pérez Giménez 2003).

Taken together, there is considerable evidence to suggest that there was a reorganisation of rural landscapes following the Christian conquest in the early 12th century. Importantly, our understanding of this period is significantly broadened due to the survival of a wide range of documentary sources. In particular, a large body of these documentary sources relate to land tenure and irrigation (Corral Lafuente 1992; Catlos 2002). This information can be placed alongside evidence from archaeological research to develop a more detailed picture (e.g. Gerrard 1999, 2003, 2011). Within the Ebro Valley, very few studies have combined documentary evidence and archaeological research to analyse evidence for change and continuity before *and* after the Christian conquests (Ortega Ortega 2010).

4.2 The sites: archaeobotanical and crop isotope evidence

4.2.1 Bureta (early medieval, 6th-early 8th century)

The site is situated c.2.5km south-west of the village of Bureta (Figure 4.4). The land immediately surrounding the site is today devoted to dry-farming/scrub pasture. However, to the south-west of the site is an irrigated area fed by an adit (water-mine) and a qanat (a sub-terranean irrigation channel) which draws water from a natural aquifer (Gerrard and Gutiérrez 2018a). In the recent past, this irrigated area (33ha) supported the cultivation of a diverse range of crops. Direct luminescence (OSL) dating of the qanat places its construction in the 13th century, with later modification in the 16th-17th centuries (Bailiff et al. 2015). Archaeological surveys by the MAS project in the vicinity of the site have also identified evidence for a late Iron Age settlement, a Roman villa and several early medieval settlements.

The site at Bureta was excavated in 2017 as part of this PhD, and the Moncayo Archaeological Survey (Gutiérrez and Gerrard 2019). This confirmed its date as an early medieval settlement and the results of field survey and geophysical prospection revealed evidence for a dense spread of probable early medieval archaeological features over an area of c.1ha (Treasure et al. in prep). Two trenches (C and P) were excavated (Figure 4.5).

In Trench C, a complex spread of archaeological features was identified, reflecting multiple phases of occupation which are probably associated with one or more structures. This included plaster/clay floor surfaces, building/levelling deposits, occupation layers, refuse deposits, pits and a wall/robber trench (Figures 4.6-4.7). Many of the contexts identified can be interpreted as secondary or tertiary deposits, probably formed through multiple, repeated activities (i.e. refuse disposal, fuel waste). This is particularly evident in the case of wall/robber trench [C7] and pit [C61] which contained a series of discrete ash-rich fills which were rich in pottery, faunal remains, eggshell and charcoal. These ash-rich fills can be interpreted as redeposited midden-type deposits. Evidence for a similar deposit rich in refuse was also identified in pit [C6], a large shallow feature containing near-complete (broken) pottery vessels and abundant faunal remains.

In Trench P, multiple phases of occupation were also identified (Figures 4.8-4.9). One of the earliest phases identified comprises a roughly constructed stone wall [P10] and an associated charcoal-rich occupation layer (P11). Immediately to the north of wall [P10], a stratigraphically later, large U-shaped pit [P37] was identified. This pit contained a series of alternating ash-rich deposits between layers of marl/clay and sand. Some of these deposits were clearly laminated, suggesting that they had been redeposited and that the pit had remained open and exposed to erosion. As in Trench C, these ash-rich deposits appear to reflect a mixture of fuel waste and refuse which have been incorporated into the pit, either deliberately or through erosion from a nearby midden-type deposit.

Interpretation of the archaeological features at Bureta is complex due to the absence of clear structural remains and the small-scale of the excavation. The evidence is indicative of a small rural settlement, with multiple phases of occupation in the early medieval period and the faunal remains recovered point towards the importance of sheep/goat herding (Gidney pers comm.). No clear evidence for earlier occupation in the Roman period or later activity in the Islamic period was identified. As part of this PhD, four direct AMS ^{14}C dates were obtained to establish the dates of the stratigraphically earliest and latest features identified in Trench C and P (Table 4.1).

In Trench C, a wheat grain from (C27), a building/levelling deposit associated with an early floor surface, (C26), returned a date of 560-650 cal CE (SUERC-81226), whilst a peach fruitstone from (C5c), a stratigraphically later pit, [C6], returned a date of 540-640 cal CE (SUERC-81225). The dates from Trench C are statistically identical, indicating occupation in the 6th to 7th century. In Trench P, a free-threshing wheat grain from (P11), a charcoal-rich occupation deposit associated with wall [P10], returned a date of 640-770 cal CE (SUERC-80216), whilst a wheat grain from (P29/30) in the stratigraphically later pit [P37] returned a date of 550-640 cal CE (SUERC-81227). The discrepancy between the two dates suggests that the sample from pit [P37] is probably residual. To clarify this, three further samples were submitted from the upper fills (P15, P18, P26) of pit [P37], however, these failed to return dates. Despite this, the AMS ^{14}C dates are consistent with the pottery dating evidence, indicating occupation in the 6th to early 8th century (pre-Islamic).

4.2.1.1 SAMPLING

Table 4.2 provides details of the contexts/features sampled. In total, 21 samples were collected in Trench C and 21 samples were collected from Trench P, with a combined volume of 1134.2L. The samples in Trench C come from a range of contexts, primarily secondary/tertiary deposits, and it was possible to collect large samples (c.40-60L) in most cases. In Trench P, a very large sample (200L) was taken from a charcoal-rich occupation deposit, (P11), representing approximately 50% of the excavated deposit. This large sample was collected since an initial assessment of a sub-sample indicated that well-preserved plant remains were present, though in low-densities. The other samples from Trench P are all from pit [P37], which were collected directly from the cleaned section to avoid mixing/contaminating the relatively thin deposits. In all cases, 100% of the visible deposit in the section was sampled.

4.2.1.2 ARCHAEOBOTANICAL EVIDENCE

The archaeobotanical results are summarised in Table 4.3, with the full dataset in Appendix 4. Due to the relatively small areas excavated and for simplicity, the assemblages from both trenches are discussed together. Reference is made to specific samples where appropriate. The 42 samples analysed produced a modest-sized assemblage, and a total of 1599 charred and 36 mineralised remains have been identified. The flots vary widely in size (5-3450ml). In general, small flots containing rare/trace quantities of charcoal and charred plant remains derive from plaster/clay floor surfaces, building/levelling deposits and occupation layers in Trench C, and from deposits of clay/marl and sand in pit [P37] in Trench P. In comparison, large flots containing abundant charcoal are primarily associated with ash-rich deposits in both trenches, though comparatively low numbers of charred and mineralised plant remains are present. The overall density of charred plant remains is low, 1.4 remains/L (range: 0.3-3.7 remains/L), and 20 samples have <10 identifiable plant remains.

The charred plant remains primarily comprise cereal grains, chaff, grape pips and wild/weed taxa, with limited evidence for pulses, fruits/nuts, millets and other crops. Other charred non-plant remains identified include low numbers of intact sheep/goat dung pellets in 14 samples and rodent droppings in sample 2, pit [C6]. Small (<4mm) amorphous charred 'conglomerations' in other samples may also be charred dung. Some of these 'conglomerations' were comparable in appearance to fragmented sheep/goat dung pellets. The mineralised plant remains include low numbers of grape pips, fig nutlets and wild/weed taxa. Other mineralised plant remains include indeterminate fragments and possible mineralised roots in seven samples, all from the ash-rich midden-type deposits. Mineralised non-plant remains include a textile fragment in sample 43 and a probable dog coprolite in sample 19.

Crops

Cereal grains and chaff dominate the assemblage, though the total number of remains (288 grains, 148 chaff items) is small considering the large number/volume of samples processed. The preservation level of cereal grains is generally poor, with unidentifiable grains forming 50% of the assemblage. The chaff remains comprise barley and free-threshing wheat rachises, alongside low numbers of culm nodes/bases. The rachises are typically very well preserved, providing secure identifications to species.

Free-threshing wheat and barley are the most common cereals recorded. Amongst the free-threshing wheat grains, the better preserved examples are all relatively short and stubby (cf. Jacomet 2006). The identifiable rachises are all from bread wheat and it is likely that the corresponding free-threshing wheat grains also derive from bread wheat. The majority of barley grains are indeterminate, though some can be identified as hulled barley with both symmetric and asymmetric grains present. The identifiable rachis segments derive from both 6-row and 2-row hulled barley. Rye grains and rachises are present in nine samples, though they form a minor component of the total assemblage. Two large (>2mm) oat grains in sample 37 may be from the cultivated species, though associated diagnostic floret bases are absent. Evidence for other cereal species is restricted to a single glume base in sample 27 which is probably from emmer wheat.

Very low numbers of foxtail and broomcorn millet grains are present. The foxtail millet grains are poorly preserved, though they probably derive from the cultivated species based on their overall morphology, thickness and embryo groove length (cf. Nesbitt and Summers 1988). Pulses form a minor component of the assemblage and the species identified include lentil, bitter vetch and probable grass pea. The grass pea seeds were recovered from two closely related samples, 32 and 33, and are tentatively distinguished from red pea based on their large size (>3mm) and very angular morphology. Oil/fibre crops form a minor component of the assemblage, with a single poorly preserved flax seed in sample 12 and five mineralised gold-of-pleasure seeds recovered from closely related samples 19 and 20. Evidence for other crops is scant, though a find of particular note is a single coriander seed/fruit in sample 31.

The fruit/nut remains (wild and cultivated) are dominated by grape, though other remains recorded include fig, mulberry, olive, sweet cherry, peach and hazelnut. Low numbers of grape remains (whole/fragmented pips, pedicles) are present in 21 samples. In comparison, sample 27 produced 213 whole pips and abundant fragments, though the density of remains is still low (1.1 items/L). The pips recorded in sample 27 are relatively short and rounded, with a similar morphology to modern wild grape (cf. Smith and Jones 1990; Mangafa and Kotsakis 1996; Bouby et al. 2018). Separation of the two forms may be resolved through morphometrics and detailed measurements of stalk length, though the pips are clearly distorted due to charring, blurring the differences between wild and domestic forms.

Wild/weed taxa

Wild/weed taxa form a large percentage (42%) of the total assemblage, corresponding to 639 charred and 20 mineralised plant remains. Most samples contain relatively low numbers of wild/weed taxa, with few species present. An exception to this is the comparatively rich assemblages of wild/weed taxa in samples 15, 16 and 17 in the ash-rich fills of wall/robber trench [C7] and samples 19, 20 and 21 in the ash-rich fill of pit [C61]. These samples contain large and diverse assemblages of wild/weed taxa, including probable arable weeds (Table 4.4, discussed below). Samples from similar ash-rich deposits in pit [P37] contain small assemblages of wild/weed taxa.

Approximately 44 different taxa/types are presented, though three taxa dominate the assemblage: *Chenopodium* sp./*Chenopodium album*-type (49%), Poaceae spp. (18%) and *Medicago* sp. (7%). In particular, *Chenopodium* spp. seeds are particularly frequent in samples containing sheep/goat dung and indeterminate charred ‘conglomerations’ which may also be dung (Figure 4.10).

The majority of weeds present can be classified as arable or ruderal species including *Chenopodium* spp., *Agrostemma githago*, *Galium* sp., *Galium aparine*, *Avena fatua*, *Lithospermum* sp., *Glaucium corniculatum*, *Malva* sp., *Neslia apiculata/paniculata*, *Polygonum aviculare*, *Polygonum convolvulus*, *Portulaca oleracea*, *Hyoscyamus niger*, *Raphanus raphanistrum*, *Urtica pilulifera* and *Vaccaria pyramidata.* Other wild/weed taxa identified to genus also include common arable and ruderal species, such as *Papaver* sp., *Silene* sp., *Solanum* sp. and *Vicia* sp.. Species typical of wet/damp habitats are only recorded in sample 27, including *Arctostaphylos uva-ursi* and *Carex* spp./Cyperaceae, suggesting that they potentially derive from the same habitat/environment. *Medicago* sp., *Plantago lanceolata* and *Hippocrepsis* sp. may grow in grasslands, though they can also be identified in arable and ruderal habitats such as fallow fields (Ruas 2005). Many of the wild/weed taxa identified have a preference for calcareous soils, reflecting the local geology of marls.

The assemblage is dominated by annual species which germinate in winter and/or spring, with early (January-June) or intermediate (April-June) flowering onset periods suggesting that they could have been in seed when cereals were harvested (June/July). The flowering durations range from short (1-3 months) to long (>6 months).

4.2.1.3 STABLE CARBON ISOTOPE ANALYSIS

In total, 16 cereal grains (6-row hulled barley, free-threshing wheat, rye) were selected for stable carbon isotope analysis. The grains all derive from Trench P and they have been selected from sample 27, (P11), and multiple closely related samples 30, 35 and 37 in pit [P37]. These contexts were selected as they contained some of the only well-preserved grains. In comparison, cereal grains associated with ‘weed-rich’ samples (see above) in Trench C were too poorly preserved to be analysed. Mean $\Delta^{13}C$ values are presented in Table 4.5 and the results are plotted in Figure 4.11. The results for each sample individually are presented in Appendix 5.

For all the cereal grains, mean $\Delta^{13}C$ values are indicative of rainfed cultivation. Mean $\Delta^{13}C$ values are 17.0 ± 0.9‰ for 6-row hulled barley grains, 15.0 ± 1.2‰ for free-threshing wheat grains and 15.0 ± 2.6‰ for rye grains. Although only a small number of grains have been analysed, none of the cereal grains $\Delta^{13}C$ values within the range expected for a well-watered (i.e. irrigated) crop.

4.2.1.4 OVERVIEW

Sample composition and formation

Analysing the assemblage on a sample-by-sample basis suggests that all the samples contain plant remains from several different sources and they can be classified as 'mixed' (see Chapter 2, section 2.2.2). The samples contain varying mixtures of different cereal species, pulses and fruits/nuts, as well as low numbers of mineralised plant remains and sheep/goat dung pellets. Consequently, material from several different sources is potentially represented including crop-processing debris food waste, background settlement noise, roofing/construction materials, fuel, animal fodder and weed seeds within dung. The similar composition of samples from the ash-rich deposits in both trenches suggests that they were probably formed though the same/similar processes.

Dung burning may (at least partly) be an important factor in the formation of the charred assemblages. Low numbers of intact and fragmented dung pellets are recorded in 14 samples, with an internal composition comprising an amorphous mass of vegetative material including traces of monocotyledon culms. No seeds were identified within the dung, though only a small number of fragmented/intact pellets are present and this cannot be taken as conclusive evidence for their absence. Small charred conglomerations recovered in other samples may also be charred dung. *Chenopodium* sp. seeds are particularly well-represented in these samples (Figure 4.10).

Chenopodium sp. seeds have been demonstrated to be widely overrepresented in samples containing burnt dung since they have a particularly high probability of surviving digestion and charring (Wallace and Charles 2013; Spengler et al. 2013; Spengler 2019). Similarly, other weeds which are likely to survive digestion and charring are also present in samples containing burnt dung including Poaceae spp. *Medicago* sp., *Galium* sp., *Vaccaria pyramidata*, *Silene* sp., *Malva* sp. and *Papaver* sp. amongst others (cf. Wallace and Charles 2013). In comparison, cereal grains typically do not survive this process in an intact and identifiable form, especially grains such as bread wheat and rye which lack protective hulls, opposed to hulled barley (Charles 1998; Derreumaux 2005; Valamoti and Charles 2005; Wallace and Charles 2013). This may be a factor in the poor preservation of cereal grains at the site. It is unclear to what extent chaff from free-threshing cereals survives digestion and charring. If some of the charred plant remains derive from dung burning, then their presence may be linked to animal fodder (Charles 1998). *Chenopodium* sp., *Medicago* sp. and Poaceae spp. are well-known sources of fodder, as are the by-products of crop-processing, millets and some fruits such as grapes/grape pressings and dried figs (Jones 1998; Foxhall 1998; Valamoti and Charles 2005).

The routine burning of dung would quickly generate large assemblages of wild/weed taxa (Miller 1984; Miller and Smart 1984). Similarly, dung fuel cakes typically incorporate other material which act as a temper, including crop-processing by-products such as chaff and other domestic waste. The excellent preservation of chaff in some samples (e.g. 15, 16, 17, 19, 20, 21) could be attributed to its inclusion within dung as a temper for fuel use, which would restrict the availability of oxygen. Despite this, it is important to note that charcoal is abundant in many samples, indicating that wood was also used as fuel source. Though wood may often be viewed as the 'ideal' fuel, in many semi-arid areas of the world dung is valued as a fuel source and often used for specific purposes (Spengler 2019).

A related factor to consider in the formation of the assemblage is that many of wild/weed taxa recorded could have been growing around the site. *Chenopodium* sp., *Polygonum convolvulus*, *Portulaca oleracea*, *Hyoscyamus niger*, *Urtica pilulifera*, *Galium aparine* and *Malva neglecta*-type are all nitrophilous and prefer slightly moister environments. These species could have thrived on nitrogen-rich soils created by stalling sheep/goats (as suggested by the presence of dung and faunal remains) and through accumulations of domestic waste in midden-type deposits (cf. Spengler 2019). The low numbers of mineralised plant remains and probable root fragments are also indicative of midden-type deposits (McCobb et al. 2003). The disposal of hot ashes/hearth debris onto middens, or the lighting of fires on the surfaces of middens, could lead to large numbers of wild/weed taxa and sheep/goat dung becoming charred (van der Veen 2007; Spengler 2019). Alternatively, accumulations of refuse may have been deliberately burnt as a means of disposal. In either case, this would lead to the charring of wild/weed taxa which are not necessarily related to cultivated fields. It is important to emphasise that dung burning is unlikely to be the sole factor contributing to the formation of the assemblage and it should be considered in tandem with other processes (Charles 1998; Smith et al. 2015). The spring/summer flowering date of the weed species would indicate that animals were present at the site in the summer months, potentially suggesting that transhumance (with summer grazing in mountains) was not undertaken.

Crop-processing and arable weeds

Disentangling the different processes forming the assemblage is challenging, though a small number of samples contain good evidence for crop-processing debris and potentially associated arable weeds. Specifically, samples 15, 16 and 17 from wall/robber trench [C7] and samples 19, 20 and 21 from pit [C61] produced comparatively rich assemblages of grains, chaff (culm nodes, rachises) and weeds (Table 4.4). The variable proportions of grain, rachises, culm nodes and weed seeds may reflect material from the early stages of crop-processing or alternatively stray chaff items present in a coarse-sieved product (Hillman 1985; Jones 1987, 1990; van der Veen 2007). A potential arable weed origin may be suggested for some of the taxa recorded.

Firstly, all the species have early/intermediate flowering onset periods and these may have been in seed when crops were harvested. Secondly, species typical of arable habitats are present including *Agrostemma githago, Avena fatua, Glaucium corniculatum, Neslia apiculata/paniculata* and *Vaccaria pyramidata*. With the exception of *Agrostemma githago*, these species have short flowering durations (1-3 months) and finish flowering early in the season (June). This last factor is a drought tolerance attribute (Jones et al. 2005) and consequently these weeds are common in rainfed cereal fields (Braun-Blanquet and de Bolós 1957; Guillerm and Maillet 1982; Cirujeda et al. 2011). Whilst *Avena fatua* can be a particularly pernicious weed of rainfed cereal fields, García Manrique (1960) noted that it was also growing in irrigated fields around Borja. *Agrostemma githago* has a long flowering period (>6 months), and it is character species of the phytosociological Secalinetea class associated with (rainfed) winter cereal fields, indicating its habitat preference/tolerance for dry conditions (Braun-Blanquet and de Bolós 1957). Short flowering durations have been linked to autumn sowing and low soil disturbance (Jones et al. 2005).

However, these samples do not solely contain material associated with crop-processing debris and some of the weeds are unlikely to be associated with cultivated cereals. Pulses, millets, fruits/nuts (especially grapes), charred dung and mineralised remains indicate the inclusion of material from other sources. Other wild/weed taxa recorded (e.g. *Chenopodium* sp., *Portulaca oleracea*) are summer annuals with medium/long flowering durations (3-6 months, >6 months) are more indicative of fertile and disturbed conditions, such as garden plots (Jones et al. 2000). These weeds may be associated with other crops or the later stages of crop-processing which can create bias towards small-seeded summer annual species (Jones 1992; Bogaard et al. 2005). Alternatively, as suggested above, some of these weeds are more likely to be associated with midden-type deposits and/or dung burning.

4.2.1.5 SUMMARY OF THE ARCHAEOBOTANICAL AND CROP STABLE CARBON ISOTOPE EVIDENCE

- The samples produced a large archaeobotanical assemblage dating to the early medieval period (6th to early 8th century). The level of preservation is generally poor, with low densities of plant remains present throughout the samples.

- The charred assemblage probably includes material from several sources, including crop-processing debris food waste, background settlement noise, fuel, animal fodder and weed seeds within dung. In particular, it is suggested that dung burning may be an important factor in the formation of the archaeobotanical assemblage based on the presence of charred sheep/goat dung pellets in 14 samples. In addition, the inclusion of domestic refuse, possible cess/latrine waste, is also indicated by the presence of low numbers of mineralised plant remains. This mixture is characteristic of midden-type deposits.

- The crop spectrum is dominated by cereals. Free-threshing wheat and (hulled) barley are the most common species. Diagnostic rachises indicate the presence of bread wheat in several samples and it is likely that all the free-threshing wheat grains are also bread wheat. Both 2-row and 6-row hulled barley are definitively identified based on the presence of diagnostic rachises. Rye forms a smaller proportion of the assemblage, whilst there is scant evidence for emmer wheat (one glume base) and low numbers of large (>2mm) oat grains may be from the cultivated species.

- There is very limited evidence for millets (broomcorn, foxtail millet) and pulses (indeterminate seeds, lentils, probable grass pea). Oil/fibre crops comprise a poorly preserved flax seed and five mineralised gold-of-pleasure seeds. The fruit/nut remains (both wild and cultivated) are dominated by grape pips, though there is also evidence for fig, mulberry, olive, sweet cherry, peach and hazelnut. An unusual crop/food plant recorded is coriander, which was identified in one sample.

- The large assemblage of wild/weed taxa is dominated by *Chenopodium* sp., Poaceae spp. and *Medicago* sp. These species, together with the presence of charred sheep/goat dung pellets, may derive from animal foddering and dung burning. Crop-processing by-products and other plants could also have been fed as a source of fodder. Several weed species are indicative of nitrogen-rich conditions, probably reflecting accumulations of refuse in midden-type deposits and the stalling of sheep/goats (as suggested by the faunal evidence and sheep/goat dung pellets).

- Probable arable weeds are present in a small number of samples together with crop-processing debris. The weeds may reflect rainfed cultivation, based on their short flowering duration and flowering period. However, the samples contain material from several sources, with spurious combinations of weeds which are unlikely to have grown together.

- The crop stable carbon isotope evidence suggests that free-threshing wheat, hulled barley and rye were cultivated under rainfed conditions. The samples all fall below the ranges expected for well-watered (i.e. irrigated crops).

4.2.2 La Mora Encantada, Bulbuente (Islamic, 10th-12th century)

La Mora Encantada is situated c.1km north-east of the village of Bulbuente (Figure 4.12). The site is situated in an area of uncultivated/scrub pasture and surrounded primarily by rainfed cereal fields, almonds and vines. To the south of the site, the ground gradually slopes towards the River Huecha, where (potentially) irrigated fields are located.

Small-scale excavations were undertaken on the site in 2016 as part of this PhD research, and the Moncayo Archaeological Survey (Gerrard and Gutiérrez 2018b). The site had been identified through fieldwalking and the visible surface remains are distributed over a small, steep hill which is bounded to the north by a large sink-hole. The archaeological remains identified include a substantial fortified wall, other smaller structures and rock-cut silos (Figure 4.13). Five small trenches were excavated to examine visible structural remains (Trench 1 and 3) and rock-cut silos (Trench 2, 4 and 5).

In Trench 1, evidence for a major stone wall [1018] and an associated smaller walled structure [1006, 1017], likely constructed from *adobes* (mudbricks), was identified (Figure 4.14). The fill of this smaller structure comprised a near-pure deposit of ash (up to 0.8m thick) which contained abundant pottery, adobes and faunal remains as well as fire-cracked stones/rubble, adobes and charcoal. This ash-deposit is likely to reflect a major conflagration, though substantial charred timbers were not identified. The deposit was excavated in spits, with an upper (1003, 1007), middle (1011, 1012) and lower (1004, 1013) layer identified. Beneath this ash-rich deposit, evidence for an occupation/floor surface (1015) and building/levelling deposit (1016) was identified. In Trench 3, evidence for a similar ash-deposit (3005) was also identified. The geophysical prospection indicates that this ash-deposit extends over an area of c.22m by 6m and it is probably contained within the footprint of a building (Treasure et al. in prep).

Trenches 2, 4 and 5 targeted rock-cut silos. Previous research suggests that features such as these are likely to contain secondary/tertiary deposits of refuse (e.g. Malalana Ureña et al. 2013; Alonso et al. 2017). This only partly proved to be the case here. Trench/Silo 2 contained only un-stratified fills and was not sampled. Trench/Silo 5, a very deep feature was largely infilled with stones/colluvium. The basal fill (5008) may also represent natural in-wash, though it produced a later medieval coin (the only find to post-date the Islamic period). In Trench/Silo 4, deposits of colluvium sealed a basal deposit (4004) rich in refuse, including faunal remains and four near-complete/broken cooking vessels (Figures 4.15-4.16).

The archaeological evidence at La Mora Encantada is indicative of a small, rural settlement. Fieldwalking data and a geophysical prospection suggests that the site could extend over an area of c.2ha (Treasure et al. in prep.). The pottery evidence recovered indicates that the site was occupied in the Islamic period (10th-12th centuries), with no clear evidence for earlier or later occupation, though only a small area has been excavated (Gerrard and Gutiérrez 2018b).

Two direct AMS ^{14}C dates were obtained to date the richest archaeobotanical assemblages associated with the lower layer (1013) of the ash-rich deposit in Trench 1 and the basal fill (4004) of Trench/Silo 4 (Table 4.6). A hulled barley grain from (1013) returned a date of 990-1160 cal CE (SUERC-74723). A hulled barley grain from (4004) returned a date of 1010-1160 cal CE (SUERC-74722). The AMS ^{14}C dates, together with diagnostic pottery evidence, place the occupation at La Mora Encantada in the 10th-12th centuries. This would suggest that the site was abandoned around the time of the Christian conquest in the early 12th century.

4.2.2.1 SAMPLING

Overall, 12 samples were collected and analysed, with a total sample volume of 570L (Table 4.7). In Trench 1 and 3, the ash-rich deposit was 100% sampled, with later sub-sampling during processing and analysis. Originally, four to five smaller samples were taken from each context/spit and later amalgamated to form one sample for each context/spit, equivalent to 40-60L. By combining several small samples, the probability of recovering rarer items increases. An additional control sample (12) was also collected from the base of the ash-rich context (1013). The basal fill (4004) of Trench/Silo 4 was also 100% sampled to account for the low-density of plant remains present. In Trench/Silo 5, examination of a sub-sample from the basal fill (5008) produced no identifiable charcoal or charred plant remains and the remaining unprocessed samples were discarded.

4.2.2.2 ARCHAEOBOTANICAL EVIDENCE

The archaeobotanical results are summarised in Tables 4.8-4.9, with the full dataset in Appendix 6. The 12 samples analysed produced a large assemblage, and a total of 3879 charred and 7 mineralised plant remains have been identified. The flots comprise widely varying quantities of charcoal and charred plant remains. Sample 1, the basal fill (4004) of Trench/Silo 4, produced a modest flot (350ml) with a small assemblage of fragmented (<4mm) charcoal and a low-density of charred plant remains (2.2 items/L). The samples from the ash-rich deposits in Trench 1 and 3 produced very large flots (>1000ml), comprising extremely abundant charcoal and variable quantities of charred plant remains. These samples also contained abundant fragments of fused, ashy/silty material which may derive from partly decomposed adobes. Samples from the upper/middle spit of the ash-rich deposit contain low densities of charred plant remains (1.3-2 items/L). In comparison, samples 7 and 12, taken from the base of the ash-rich deposit (1013), contain the highest densities of charred plant remains (31.6 items/L). Sample 10, from the ash-rich deposit (3005), also contains a high density of charred plant remains (8.6 items/L).

The charred plant remains comprise abundant cereal grains, chaff, fruits/nuts (primarily walnut, grape and fig) and wild/weed taxa, with smaller quantities of millets, flax and pulses. Sample 7/12 also contains charred sheep/goat dung pellets and abundant conglomerations of charred material in the 2mm and >4mm fractions. These conglomerations are probably also charred dung based on their internal composition (amorphous matrix of vegetative material), though they appear to have become fused to other material, notably cereal straw and culm nodes. As is outlined below, this material probably reflects a combination of animal bedding, fodder and dung.

Very low numbers of mineralised plant remains present include fig nutlets, grape pips/seeds, millets and a sweet cherry fruitstone. Other charred non-plant remains include rare/trace quantities of unidentified insects and textile fragments, especially in sample 7/12.

Crops

Cereal remains (grains, chaff) are abundant in samples 1, 7/12 and 10. In total, the assemblage comprises 442 cereal grains and 760 chaff remains (rachis segments, culm nodes). The level of preservation for cereal grains is generally moderate to good, with unidentifiable grains forming 23% of the assemblage. Chaff is typically very well preserved and near-perfectly preserved rachis segments are present in some cases with hairs still visible and several conjoined segments (Figure 4.17). Sample 7/12 produced abundant culm nodes and culm/straw fragments, alongside lower number of indeterminate light chaff fragments which are probably lemmas/paleas. Straw fragments were identified within charred dung.

Hulled barley grains form 40% of the grain assemblage, with both symmetric and asymmetric grains recorded indicating the presence of 6-row hulled barley. The ratio of symmetric to asymmetric grains is 0.76 which is higher than the theoretical ratio of 0.5 in 6-row hulled barley (Jacomet 2006). This may indicate that 2-row hulled barley is present, though it should also be borne in mind that crop-processing and charring can artificially skew the proportions of symmetric to asymmetric grains (Jones 1996). Well-preserved 6-row hulled barley rachises are common, forming 18% of the identifiable rachises. Indeterminate barley rachises with a morphology similar to 2-row types are present, however, none of the rachises can be securely assigned to 2-row barley. Three probable naked barley grains are also present, with a characteristic rounded form and wrinkled grain surface (Jacomet 2006). In sample 7/12, the ratio of barley rachises to grain is 1.8.

Free-threshing wheat grains only form 13% of the assemblage, though this may reflect the poorer preservation of bread/durum wheat during charring making identifications more difficult (Boardman and Jones 1990). The free-threshing wheat grains are highly variable in morphology with short stubby forms, long slim forms and intermediate variants all recorded (cf. Jacomet 2006). Both bread and durum wheat are definitively identified based on the presence of diagnostic rachis segments, particularly in samples 7/12 and 10. Combined together, free-threshing wheat rachises form 33% of the identifiable rachises. In sample 7/12, the ratio of free-threshing wheat rachises to grain is very high (3.4), exceeding the theoretical ratio (0.33) in an ear (Jones 1990).

Evidence for other cereal species is comparatively slight. Rye grains only form 5% of the grain assemblage, though rachises are better represented, forming 13% of the assemblage. Five large (>2mm) oat grains have been identified, though the only diagnostic floret base is from *Avena fatua*. There is no secure evidence for other cereal types, though a small number of indeterminate wheat grains are relatively slim (<2.5mm) and could possibly derive from a glume wheat species. No diagnostic glume bases/spikelet forks are present.

Millets are present in all the samples and the identifiable grains are primarily broomcorn millet (85%). Sample 7/12 produced a small conglomeration of >10 fused broomcorn millet, as well as two mineralised grains. The presence of both hulled/unhulled and immature/mature grains is noted in sample 7/12. Foxtail millet only forms 5% of the millet assemblage, whilst indeterminate broomcorn/foxtail millet grains make up the remaining 10%. Evidence for pulses is rare, with lentil, bitter vetch, pea and probably grass pea identified. Well-preserved flax seeds are present in multiple samples with a total of 68 seeds identified. A conglomeration of >10 fused flax seeds is present in sample 7/12. No remains of flax capsules have been identified.

Fruit/nut remains (both wild and cultivated) are very abundant, including walnut, fig, mulberry, sweet cherry, blackberries, possibly pomegranate, olive and grape. Unidentified fruitstone/nutshell fragments are also common and other species may be represented amongst these remains. Sample 7/12 produced the richest assemblage of fruit/nut remains, comprising 201 walnut shell fragments, 401 fig nutlets, a fig fruit fragment, >22 mulberry fruitstones, 12 sour/sweet cherry stone fragments, a whole olive, 178 blackberry fruit stones (as well as other blackberry species) and 153 grape pips. Some fruit remains were identified embedded within charred dung: fig, mulberry, grape and blackberry.

The grape remains are of particular note since they include abundant pips (whole/fragmented) and pedicles, alongside low numbers of whole berries (including fragments), immature whole berries and 'pressed' skins (Figure 4.18). These remains are comparable to the by-products of grape pressings (cf. Margaritis and Jones 2006). A possible fragment of a pomegranate seed is also present in sample 7/12 which is identified based on the presence of a distinctive central groove and a 'tarry' appearance (Fuller and Pelling 2018).

Wild/weed taxa

In total, 996 remains of wild/weed taxa have been identified, representing approximately 47 different taxa/types, excluding remains of possible wild food plants such as blackberry. Sample 7/12 contains 65% of the total assemblage of wild/weed taxa. Poaceae spp. are the most common remains, which are present in all the samples and form 36% of the assemblage. Other common wild/weed taxa include Asteraceae, *Chenopodium* sp. and cf. *Reseda* sp..

Many of the taxa recorded can be classified as growing in arable or ruderal habitats including *Agrostemma githago*, *Avena fatua, Chenopodium album*-type, *Convolvulus arvensis, Fumaria* sp., *Lithospermum* sp., *Polygonum convolvulus, Polygonum aviculare, Portulaca oleracea, Raphanus raphanistrum, Silene* sp., *Solanum nigrum*, *Vaccaria pyramidata* and *Verbena officianalis*. With the exception of *Verbena officianalis* and *Convolvulus arvensis*, these species are all either winter or summer annuals with early-intermediate flowering onsets and flowering durations ranging from short (1-3 months), medium (4-5 months) to long (>6 months). This includes species which can tolerate drier conditions, finish flowering early in the season and have short flowering durations (e.g. *Avena fatua*, *Vaccaria pyramidata*). In comparison, other species recorded are nitrophilous with a preference for moister environments typically found in gardens, ditches, near irrigation channels or other disturbed habitats (e.g. *Chenopodium album*-type, *Portulaca oleracea, Verbena officianalis*).

Taxa typical of wet/damp and/or grasslands habitats are poorly represented including *Carex* spp., cf. *Thalictrum* sp. and a capsule of wild *Linum* sp. comparable in size to *Linum catharticum*. One large culm node and culm base, c.7mm in width, was recovered from sample 7/12 which may be from a reed (*Phragmites*) or large grass (*Arundo donax*). *Sambucus* sp. seeds are very abundant in sample 7/12, and these are probably from *S. racemosa* (a tree/shrub) based on their morphology and size, rather than or *S. elubus* (a weed species). Possible *Sambucus* sp. rachises (stalks supporting the inflorescence) are also abundant in sample 7/12, suggesting that whole panicles have been charred. *Sambucus* sp. seeds were identified embedded within charred dung. The large number of blackberry fruit stones are indicative of shrub/woodland edge habitats, though this species can also be commonly observed growing today in moisture-rich areas (e.g. edges of irrigation channels, abandoned gardens) (personal observation).

4.2.2.3 STABLE CARBON ISOTOPE ANALYSIS

In total, 65 cereal grains (6-row hulled barley, free-threshing wheat, rye), 24 rachises (bread wheat, durum wheat) and 5 pulse seeds (lentils) were selected for stable carbon isotope analysis. The samples are from the basal fill (4004) of Trench/Silo 4, an ash-rich deposit (3005) in Trench 3 and multiple related contexts/spits from the ash-rich deposit in Trench 1, grouped together under context (1013) for simplicity. Rachis segments of bread wheat and durum wheat were analysed to assess if there is any difference in cultivation practices between these two species since free-threshing wheat grains cannot be separated. Rachis $\Delta^{13}C$ values may also provide an indication of growing conditions before the grain filling period (Wallace et al. 2013). Mean $\Delta^{13}C$ values are presented per context in Table 4.10 and box plots of the results for the site as a whole are presented in Figure 4.19. The results for each sample individually are presented in Appendix 7.

Mean $\Delta^{13}C$ values for 6-row hulled barley are 15.6 ± 1.5‰ in context (1013), 15.3 ± 1.1‰ in context (3005) and 15.8 ± 1.9‰ in context (4004). The mean $\Delta^{13}C$ value for all the 6-row hulled barley samples (n = 41) is 15.6 ± 1.6‰. These results are indicative of rainfed cultivation, and clearly fall within the 'poorly watered' ranges defined by Wallace et al. (2013) and Flohr et al. (2019). The large range of values (i.e. >1‰), particularly in context (4004), suggests that the samples derive from different fields and/or different years. The mean $\Delta^{13}C$ value for rye, 15.1 ± 1.0‰, is probably also indicative of rainfed cultivation. Kottmann et al. (2014) recorded that rye growing under 'severe drought' had a Δ^{13}C value <18‰, though further modern comparative data is required.

Mean Δ^{13}C values for free-threshing wheat are 16.9 ± 0.9‰ in context (1013) and 17.4 ± 1.1‰ in context (3005), whilst the mean Δ^{13}C value for all the free-threshing wheat grain samples (*n*= 19) is 17.0 ± 0.9‰. Most of the samples fall broadly within the range expected for an irrigated crop (>17‰). This is equivalent to the 'well-watered' band defined by Wallace et al. (2013), whilst 37% (7/19) of the samples are within the conservative 'well-watered' band (>17.5‰) defined by Flohr et al. (2019). This interpretation is also supported by the higher Δ^{13}C value for free-threshing wheat (+1.4‰) compared to hulled barley. If wheat and barley were cultivated under the same conditions, 6-row hulled barley would be expected to have a higher Δ^{13}C value, potentially c.+2‰ higher (Voltas et al. 1999; Jiang et al. 2006; Aniya et al. 2007).

The corresponding bread wheat and durum wheat rachis Δ^{13}C values can help to corroborate the interpretation of the free-threshing wheat grain Δ^{13}C values (cf. Wallace et al. 2013). In context (1013), the mean Δ^{13}C values for bread wheat and durum wheat rachises are 17.9 ± 1.9‰ and 17.6 ± 1.5‰ respectively, whilst in context (3005) the mean Δ^{13}C value for durum wheat rachises is 19.7 ± 0.5‰. There is no statistically significant difference between the Δ^{13}C value for bread and durum wheat rachises (Mann-Whitney *U*-Test: U=53, p=0.41), suggesting both crops may have been cultivated under similar conditions. The higher Δ^{13}C value in rachises compared to free-threshing wheat grains corresponds to a known pattern for ^{13}C discrimination to be higher in rachises (Merah et al. 2002; Wallace et al. 2013). Rachis typically have a Δ^{13}C value +1.7-2‰ higher than the corresponding grain, though the difference can be as little as c.0.5‰. High Δ^{13}C values for durum wheat rachises (19.2-20.7‰) in context (3005) are indicative of irrigation, though only a small number of samples were analysed (n=5) and it is possible that the rachis segments derive from a single cereal ear. Despite this, the high rachis Δ^{13}C values in context (3005) are corroborated by a slightly higher mean free-threshing wheat grain Δ^{13}C value of 17.4 ± 1.1‰, compared to context (1013) which has a mean Δ^{13}C of 16.9 ± 0.9‰. Further research may help to clarify the potential range of rachis Δ^{13}C values which could be expected for rainfed and irrigated conditions in semi-arid environments.

Considering the large difference in mean Δ^{13}C values between hulled barley and free-threshing wheat (1.3‰), the most likely explanation is that free-threshing wheat was irrigated, though the cultivation of naturally wetter soil may also be a factor in this. A hypothesis suggested here is that hulled barley (and possibly also rye) was cultivated in the more exposed areas surrounding the site, whilst free-threshing wheat was cultivated in fields situated towards valley bottom and River

Huecha. These fields are potentially irrigable (and they currently are), though the date of the *acequia* running below the site is currently unknown.

The mean $\Delta^{13}C$ value for lentils is 16.1 ± 0.5‰. This is below the 'well-watered' range (>17‰) defined by Wallace et al. (2013). This does not exclude the possibility that lentils were irrigated, since irrigated lentils can have $\Delta^{13}C$ values between 16-17‰.

4.2.2.4 OVERVIEW

Sample composition and formation

The archaeobotanical assemblages in Trench 1 and Trench 3 formed through similar processes. These ash-rich deposits probably derive from a major conflagration and consequently *any* plant remains present within the structure could have become charred. This could include deliberately stored crops/crop components such as cleaned cereal grains or the valuable by-products of crop-processing such as straw and chaff. If structures were used for several years the remnants of previously stored material and 'stray' items could also create background 'noise'. Other materials used within the construction of the building are also a potential source of plant remains such as flooring or roofing. Similarly, chaff and weeds could have been incorporated into the production of adobes[6] and these could have become charred and dispersed throughout the deposits (cf. Delgado and Guerrero 2006; Henn et al. 2015). Consequently, whilst the charred plant remains are within a primary deposit, the assemblage probably also contains material of a secondary or tertiary origin (cf. Fuller et al. 2014).

The rich and diverse assemblage of charred plant remains recovered, particularly in samples 7/12 and 10, clearly derive from multiple origins and it is suggested that, in part, this assemblage includes stable manure (sensu Kenward and Hall 1997). Different cereal species (bread wheat, durum wheat, hulled barley, rye) are present alongside broomcorn millet, flax, fruit/nut remains and wild/weed taxa. The large numbers of culms/straw fragments, culm nodes and rachises, together with abundant wild/weed taxa, clearly reflect material from the early stages of crop-processing. It is not uncommon for mixtures of different cereals, together with other crops, arable weeds, grape-pressings and other plants to be fed as a source of fodder. Foxhall (1998) even suggests that the provisioning of animal fodder was almost entirely dependent on agricultural residues such as these.

[6] Two small fragments of partly charred adobes were disaggregated in water and were found to only contain flecks of charcoal/charred plant remains.

The argument for stable manure is strengthened by the presence of charred dung. Charred sheep/goat dung pellets are frequent in sample 7/12, together with abundant conglomerations with an amorphous matrix of vegetative material closely resembling charred dung. It is also possible that dung from larger animals such as cattle is present as this is less likely to preserve in a diagnostic form. Sheep/goat and cattle were identified in the faunal assemblage (Gidney pers comm.). Identified plant remains within the charred sheep/goat dung pellets and conglomerations include cereal straw, cereal culm nodes, grape pips, fig seeds, mulberry fruitstones, *Rubus* sp. fruitstones and *Sambucus* sp. fruitstones. These latter two species are particularly common. It is interesting to note that probable *Sambucus* sp. rachises are also present suggesting that panicles (inflorescences) have become charred. Small twigs are also abundant within the assemblage. Together this material probably could reflect leaf foddering or vegetation browsing by sheep/goats on field edges (Halstead 1998; Halstead et al. 1998). It has been highlighted that the by-product of leaf foddering (small, dry twigs) can be gathered up and stored since this material makes an excellent fuel for hearths or bread ovens (Zapata Peña et al. 2003). Though wild/weed taxa (i.e. arable weeds) were not recorded within the dung, many of the species present are likely to have survived digestion and charring (cf. Wallace and Charles 2013). Taken together, there is good evidence to suggest that the assemblage includes animal fodder and stable manure (sensu Kenward and Hall 1997). However, it is also evidence that material from other origins also present and animal fodder/stable manure can only partly account for the range of plant remains recorded.

In Trench/Silo 4, the recovery of faunal remains and discarded pottery cooking vessels suggests the disposal of refuse (Gerrard and Gutiérrez 2018b). This interpretation would fit with the archaeobotanical evidence, which includes a mixture of different cereal species, broomcorn millet, fruits/nuts, flax, pulses and wild/weed taxa. Many of the cereal grains and flax seeds are very well preserved suggesting that they probably do not derive from background settlement waste, but rather are likely to have been deposited along with other refuse and quickly buried. The more poorly preserved items may reflect charring at higher temperatures and/or the subsequent redeposition of sweepings from floors or hearths.

Grape pressings?

Sample 7/12 produced probable evidence for the by-products of grape pressings, comprising whole pips, pip fragments, pedicles, whole berries, berry fragments, immature whole berries and 'pressed' skins (Figure 4.18). Though only a small number of the diagnostic 'pressed' skins are present, these remains are morphologically comparable to the experimental charred by-products of grape pressing (Margaritis and Jones 2006; Valamoti et al. 2007). 'Pressed' skins are not produced by charring whole grapes or raisins, strengthening the case that they derive from grape pressings.

Crop-processing and arable weeds

As outlined above, sample 7/12 contains a large assemblage of crop-processing debris, comprising culm/straw fragments, culm nodes, rachises and grains, which derive from 6-row hulled barley, rye, bread wheat and durum wheat (Table 4.11). The crop isotope evidence indicates that these crops were grown under different conditions, though since they are all free-threshing cereals they could theoretically have been processed together (see Hillman 1985; Jones and Halstead 1995). The presence of culms/straw, culm nodes and (sub-)basal rachises suggests the harvesting of ears with the straw (Hillman 1985), though it is also possible that straw could have been harvested separately from the ears at a later date (Halstead 2014:86-88). Harvesting of straw could also reflect the requirement for animal fodder (Halstead 2014:50-51). The high ratio of chaff (culm nodes, rachises) to grain, and weed seeds to grain in samples 7/12 and 10 indicates that the material derives from the early stages of crop processing (see Jones 1984; van der Veen 2007). In comparison, the low ratios in sample 1 are indicative of a (semi-)cleaned cereal crop, suggesting that this sample contains domestic refuse, probably linked to food preparation.

It is likely that many of wild/weed taxa are associated with the cultivation of cereal crops and most of the species could have been in seed at the time of harvest (June/July). However, the samples are all classified as 'mixed' (see Chapter 2, section 2.2.2) and the weeds could equally be associated with other crops including flax and millet, or from crops cultivated under different conditions as suggested by the stable isotope analysis. These factors have probably created spurious combinations of species that did not actually grow together.

Despite this, the rich assemblage of wild/weed taxa can provide some information on the nature of cultivation conditions. Firstly, some of the weeds are probably associated with cereals. *Avena fatua* and *Vaccaria pyramidata* are present; these tolerate dry conditions, have short flowering durations (1-3 months) and finish flowering early in the season (June) to cope with droughts (Jones et al. 2005). Short flowering durations have also been associated with autumn sowing and low soil disturbance. Consequently, these species have been commonly associated, though not invariably, with autumn sown (rainfed) cereal fields. Similarly, *Agrostemma githago* is character species of the phytosociological Secalinetea class associated with rainfed winter cereal fields

(Braun-Blanquet and de Bolós 1957), whilst *Raphanus raphinstrum* is also typical of arable habitats.

Secondly, summer annual species with medium/long flowering periods (3-6 months, >6 months) a preference for nitrogen-rich and moister habitats are well represented (e.g. *Chenopodium album*-type, *Convolvulus arvensis, Fumaria* sp., *Polygonum convolvulus, Polygonum aviculare, Portulaca oleracea, Solanum nigrum*, *Verbena officianalis*). These weeds are primarily annuals, associated with fertile and disturbed habitats in areas such as gardens, ditches or the edges of acequias/irrigated fields. *Convolvulus arvensis* reproduces by vegetative propagation and this functional attribute is commonly associated with more intensively disturbed habitats such as gardens or in fields where crop-rotation/fallowing is used (Bogaard et al. 1999; Jones et al. 2000). However, whilst Convolvulus arvensis has a preference for nitrogen-rich and moist soils, it has been observed growing in irrigated and rainfed fields in Borja (P. Halstead pers comm.). Polygonum aviculare may have been a common weed in fallow fields and in cereal stubble after harvesting (P. Halstead pers comm.). Low numbers of species with preference for wet/damp conditions (Cyperaceae, *Carex* spp., cf. *Thalictrum* sp., possibly reeds) could have grown along the edges of acequias or irrigated fields (cf. Miller 1982: 158-160, 2011:65-66; Riehl 2010; Marston and Miller 2014). However, it should be noted that species with a preference for wet/damp habitats can also grow in poorly drained rainfed cereal fields (Hillman 1991).

4.2.2.5 SUMMARY OF THE ARCHAEOBOTANICAL AND CROP STABLE CARBON ISOTOPE EVIDENCE

- The samples produced a large and generally very well-preserved archaeobotanical assemblage dating to the Islamic period (10th-12th centuries).

- In Trenches 1 and 3, an ash-rich (conflagration?) deposit was sampled and this produced a rich and diverse assemblage of charred plant remains including abundant crop-processing debris, millets, flax, fruits/nuts and wild/weed taxa. Charred sheep/goat dung is also present. This range of plant remains reflects a mixture of material from several sources, though it is suggested that stable manure is present. In comparison, in Trench 4 from the basal fill of a silo, an assemblage of cereal grains and other remains (flax, pulses, weeds) can be interpreted as a mixed refuse deposit.

- Cereals are very common, and the species identified include free-threshing wheat, 6-row hulled barley, rye and possibly oat. Large numbers of diagnostic bread wheat and durum wheat rachises are present. There is no conclusive evidence for 2-row hulled barley.

Other crops identified include broomcorn millet, foxtail millet, flax and pulses (pea, lentil, probable grass pea, bitter vetch). Fruit/nut remains are very abundant, with grape, fig, mulberry, olive, sweet cherry, walnut and blackberry all recorded. Evidence for grape pressings has also been identified.

- A rich and diverse assemblage of wild/weed taxa are present, particularly in the samples from Trench 1 and 3. The assemblage can be classified as 'mixed' and it is not possible to associate specific weeds with crops. Despite this, some of the species present are typical of wet/damp habitats and these could reflect irrigation. Similarly, ruderal species with a preference for nitrogen-rich and slightly moister environments are well represented and these species are typical of environments such as ditches, gardens or irrigated areas. However, there are also species which are typical of drier conditions and these may be linked to rainfed fields.

- The crop stable carbon isotope results indicate cultivation under a range of different conditions. The $\Delta^{13}C$ values for free-threshing wheat are indicative of an irrigated crop and these results are to some extent corroborated by the analysis of the corresponding bread and durum wheat rachis segments. In comparison, the $\Delta^{13}C$ values for hulled barley clearly indicate a rainfed crop. Rye may also have been cultivated in rainfed fields. It is unclear from the small number of lentil seeds analysed whether they were irrigated.

4.2.3 Iglesia de San Miguel, Ambel (Islamic, early 12th century)

The Iglesia de San Miguel is a 14th century church located within the centre of the small village of Ambel (Figure 4.20). The village covers an area of sloping ground, at the foothills of the Sierra del Moncayo which rises to 2314m (a.s.l.). The church is associated with the adjacent Casa Conventual de Ambel (see below), a 12th-13th century building complex originally constructed by the Templars, and later passing to the Hospitallers in the 14th century (Gerrard 2003a). The site is centred around an earlier, fortified tower, probably dating from the Islamic period. In 2007, excavations were undertaken within the footprint of the church during restoration works (Blanco Morte 2007).

The excavations identified a range of archaeological features associated with the earlier fortified, Islamic tower (Blanco Morte 2007). The features identified include a perimeter enclosure wall and 11 silos surrounding the base of the tower (Figure 4.21). These silos contained typical refuse-type deposits, characterised by faunal remains, coins and pottery which date the infilling of the features to the early 12th century (i.e. around the time of the Christian conquest, c.1121). Other features identified may also be of Islamic date including a small tank and an area of burning, possibly a hearth.

4.2.3.1 SAMPLING

Overall, 7 samples were collected, with a total sample volume of 14.1L (Table 4.12). Four samples were collected from the fills of silos [2] and [9]. Two samples were also collected from the fill of the small tank [C1] and the hearth [H1].

4.2.3.2 ARCHAEOBOTANICAL EVIDENCE

The archaeobotanical results are summarised in Table 4.13, with the full dataset in Appendix 8. The seven samples analysed produced a very small assemblage of plant remains, with 19 charred and 2 mineralised remains identified. The flots are very small (2-100ml), with varying quantities of charcoal and identifiable plant remains are either absent or present in trace quantities. An exception to this is sample 1 from Silo 2, which produced a small assemblage of cereal grains, chaff, millets, grape and wild/weed taxa. The density of remains in silo 2 is modest, 4 items/L and the level of preservation is good.

Crops

The cereal grains present include unidentifiable grains (and fragments), rye and free-threshing wheat. Chaff remains comprise one well-preserved 6-row hulled barley rachis and a culm node which is probably from a cereal. Millets are represented by one indeterminate grain and a mineralised broomcorn millet grain which is still retained within its hull/chaff. Fruit/nut remains include a grape pedicle and an indeterminate fleshy fruit fragment which may also be from a grape.

Wild/weed taxa

In total, remains of 12 wild/weed taxa have been identified, including *Chenopodium* sp., an unidentified small seeded Fabaceae, *Malva* sp., Lamiaceae, *Papaver* sp. Rubiaceae and Poaceae spp.. A single bio-mineralised Boraginaceae seed is also present. These species could grow in a wide range of habitats, though they are common in arable and ruderal habitats.

4.2.3.3 OVERVIEW

Sample composition and formation

With the exception of sample 1, the absence/near-absence of plant remains (excluding charcoal) probably partly reflects the small size of the samples collected, rather than their actual absence. In sample 1, the small assemblage of cereal grains, chaff, millets, possibly grape and wild/weed taxa could reflect refuse, background settlement noise or crop-processing debris which has been redeposited into the silo. The use of silos to dispose of refuse is well documented in medieval/Islamic contexts (cf. Malalana Ureña et al. 2013; Alonso et al. 2017). The assemblage is well-preserved suggesting that the material was probably quickly buried once charred. The mineralised broomcorn millet grain could derive from a midden-type deposit rich in organic waste, or an ingested seed which has not broken down. Though the assemblage is small, the good preservation suggests that an appropriate sample size between 40-60L in size would have recovered a relatively large and interpretatively meaningful assemblage.

4.2.3.4 SUMMARY OF THE ARCHAEOBOTANICAL EVIDENCE

- The samples produced a small assemblage dating to the Islamic period (early 12th century). Nearly all of the remains derive from one feature, Silo 2. Despite this, a surprisingly diverse and well-preserved assemblage of both charred and mineralised remains are present.

- The assemblage probably reflects a mixture of material from several sources which has become incorporated into the silo as refuse.

- The crops identified include free-threshing wheat, rye, 6-row hulled barley, broomcorn millet and grape.

- The small assemblage of wild/weed taxa recovered are probably all arable and ruderal weeds.

4.2.4 Palacio de Bulbuente, Bulbuente (later medieval, 14th century)

The Palacio, or Castillo, Bulbuente is a multi-period building complex situated within the southern end of the small village of Bulbuente, on the northern bank of the River Huecha (Figure 4.22). A settlement at Bulbuente is referred to in 12th century documentary sources (i.e. after the Christian conquest) and, in the 13th century the town and *castillo* became the property of the nearby Cistercian monastery at Veruela (González Palencia 1945; Cabanes Pecourt 1984). The building complex was an abbot's palace, forming part of the monastery's extensive land holdings and network of properties along this part of the Huecha Valley

The present-day building complex at Bulbuente comprises an early (possibly Roman or Islamic) fortified tower and an adjoining 15th-16th century brick and rammed earth (*tapial*) palace (Figures 4.23). Excavations at the site (2013-2014) primarily identified archaeological deposits dating to the later medieval and post medieval periods (Gerrard and Gutiérrez 2014). In particular, beneath the standing 15th-16th century palace there is an earlier structure which was destroyed in a major conflagration in the 14th century. The destruction of the complex is probably linked to the war of the two Peters (1357-1369), between Pedro IV of Aragón and Pedro I of Castilla, which is known to have affected the area (Cabanes Pecourt 1984; Gerrard 2003:43). The present-day building complex, dating predominantly to the 15th-16th centuries, seals these earlier deposits. Intensive bulk-sampling was carried out in Trench Z (Gerrard and Gutiérrez 2014).

The mid-14th century destruction/conflagration deposit was highly distinctive, containing abundant burnt adobes, heat-shattered stones, whole pottery vessels, charred timbers/beams and the near-complete remains of charred door constructed from walnut (Figure 4.24). This destruction/conflagration deposit was identified in Trenches H, B and Z. In Trench Z, it comprised three distinct layers:

- (Z7 I): An upper layer of burnt/degraded *adobes* and roof tile. This context was not sampled since it may have been partly truncated in the 15th-16th centuries.
- (Z7 II): A middle layer consisting of a mixture of burnt *adobes*, pottery and charred timbers/beams. This context is equivalent to (B53) in Area B.
- (Z7 III): A basal layer of near-pure charcoal and heat-shattered stones.

Beneath this destruction/conflagration deposit was a burnt occupation layer (Z22). This context is equivalent to (H104) in Trench H and (B57) in Trench B. Limited evidence for earlier archaeological deposits, pre-dating the 14th century structure, were also identified. This included a large pit containing abundant iron slag and associated deposits, possibly Roman, however, the archaeobotanical evidence recovered appears to be intrusive within this feature from the 14th century destruction/conflagration deposit (see below).

Three direct AMS ^{14}C dates were obtained on the destruction/conflagration deposit (Table 4.14), two from its southern edge in Trench H (H104) and one from its northern edge in Trench B (B500). A barley and oat grain submitted from (H104) returned dates of 1220-1390 cal CE (SUERC-68397) and 1290-1420 cal CE (SUERC-68398). A sample of elm roundwood charcoal submitted from B500 returned a date of 1280-1400 cal CE (SUERC-68396). Several attempts were made to obtain a further direct date on the destruction/conflagration deposit in Trench Z, however, these failed due to an insufficient carbon yield. An emmer wheat grain was also submitted from a slag-filled pit [B35/45] pre-dating the destruction/conflagration deposit in Trench B. The sample returned a date of 1260-1390 cal CE (SUERC-74721), suggesting that the archaeobotanical assemblage is intrusive within this feature as suspected.

4.2.4.1 SAMPLING

Overall, 52 samples were collected, with a total sample volume of 481L. The majority of samples come from Trench Z (Table 4.15). Samples 1-7 are not included in Table 4.15 since these are post-medieval in date. These deposits were comprehensively sampled in a grid due to their large size and to identify potential evidence for spatial patterning in the distribution of archaeobotanical evidence. A minimum of one c.20L bulk-sample, or 100% of the deposit, was collected in each grid square, often in the form of multiple smaller samples.

4.2.4.2 ARCHAEOBOTANICAL EVIDENCE

The discussion below only focuses on the 43 samples collected from the mid-14th century destruction/conflagration deposits in Trench H (context H104), Trench Z (contexts Z7, Z22) and Trench B (contexts B53, B57). The archaeobotanical results are summarised in Table 4.16, with the full dataset in Appendix 9. The 43 samples analysed produced a large assemblage of plant remains, with 7040 charred remains and 8 mineralised remains. Samples from the destruction/conflagration deposits, (Z7) and (B53), produced very large flots (c.700ml on average), containing extremely abundant charcoal, particularly the base of the destruction deposit (layer III). The burnt occupation layer in Trench B, (B57), also produced a very large flot (1500ml). In comparison, samples from the burnt occupation layer in Trench Z, (Z22), and Trench H, (H104), produced small flots (c.75ml on average) with little charcoal and variable quantities of charred plant remains.

The assemblage is dominated by cereal grain, whilst chaff and wild/weed seeds are comparatively rare in most samples (excluding rye). Millets, pulse seeds and fruit/nut remains are also present in low numbers throughout the samples. The highest density of plant remains were recovered in samples 19 (60 items/l) and 20 (44 items/l) from Trench B. Samples in Trench Z vary in the density of plant remains present (typically 3-14 items/L), with the highest density in samples 39, 51 and 75 from context (Z7) in Grid C-3 (24 items/l), and sample 22 (39 items/L) from context (Z22) in Grid D-2. In sample 9, Trench H, the density of charcoal and plant remains is low (0.9 items/L). Other charred non-plant remains present abundant burnt construction/building material (adobes, tiles) and occasional insects and textile fragments. Charred sheep/goat dung pellets are present in low numbers in two samples.

Crops

Free-threshing wheat, hulled barley and rye occur in remarkably similar proportions in all the different grid squares (Figure 4.25). The free-threshing wheat grains are variable in morphology and a small number of rachises indicate the presence of both bread and durum wheat. The barley grains which can be identified to species are overwhelmingly hulled, with both symmetric and asymmetric grains present indicating the presence of 6-row hulled barley. The ratio of symmetric:asymmetric grains is 1:3, which is higher than the theoretical ratio of 1:2 (Jacomet 2006). Rachises of 6-row hulled barley are also present. None of the rachises identified are from 2-row types, though it cannot be excluded that 2-row hulled barley is present. Two probable grains of naked barley have been identified based on their characteristic rounded form and 'wrinkled' grain surface (cf. Jacomet 2006). Low numbers of tail/runt grains from both free-threshing wheat and hulled barley are present.

Rye grains are near-perfectly/perfectly preserved in many cases and they could be easily separated from wheat. Rye rachis segments are particularly abundant in the samples, especially in samples 39 and 51 from grid C-3. This grid potentially contains the partial remains of rye straw based on the presence of rye grains, long conjoined rachis segments, (sub-)basal rachises, as well as abundant culm nodes, culm/straw fragments, lemma/palea fragments and awns which also probably derive from rye. In total, a large number (n=368) rachis segments are present, however 75% of these derive from only 6 samples.

Large (>2mm) oat grains are common, though they are present in smaller quantities than other cereals. The oats are probably from cultivated common oat due to their large size and morphology, though the only floret bases identified derive from *Avena* fatua. The presence of *A. fatua* could account for the comparatively sparse small <2mm oat grains. Low numbers of emmer wheat and possible einkorn wheat grains are present throughout the samples. The emmer wheat grains have the characteristic long, narrow form and dorsal 'hump' as defined by Jacomet (2006). A small number of grains may be from einkorn with slightly convex ventral surface and high dorsal ridge. However, no glume bases or spikelet forks of either species are present.

Other crops are distributed throughout the samples, though they are typically present in low numbers including millets, pulses and flax. A total of 199 millet grains are present and identifiable grains are primarily from broomcorn millet (97%), including both hulled and unhulled grains. Only one sample, 19, produced a probable foxtail millet grain. Pulse seeds are common and broad bean is by far the most common species recorded (*n*=104). The broad bean seeds are relatively large, measuring 11.9mm (length), 8.2mm (width) by 6.1mm (breadth) on average, with the largest length of one bean measuring 13.8mm. This suggests that these remains are approaching the dimensions of *Vicia faba* var. *major* (Neef et al. 2011; Zohary et al. 2012). Similarly, the broad bean seeds have the characteristic morphology of *V. faba* var. *major*, as opposed to the short, rounded morphology of *V. faba* var. *minor*. One bean has a possible weevil hole, probably from the bean weevil, *Bruchus rufimanus*. Other pulse crops identified include pea, lentils, bitter vetch and an unidentified *Vicia/Lathyrus*-type species. Vetches are also present, though they are poorly preserved and could be a weed. Evidence for other crops is slight, within a single flax seed recorded in sample 68.

Remains of fruits/nuts are present in most samples, though the number of remains is generally low (excluding grape). The species (wild and cultivated) identified include grape, fig, mulberry, olive, blackberry, possibly plum, sweet cherry, peach, almond, hazelnut and walnut. Analysis by grid square indicates that fruit/nut remains are particularly common in samples 39 and 51 from C-3. There is, however, no clear evidence for spatial patterning in the distribution of the fruit/nut remains. Grape is the most common species with whole pips, fragments and pedicles present in most contexts, though they are often poorly preserved. Low numbers of mineralised pips are present in samples 27 and 63. Other grape remains include low numbers of whole charred berries, particularly in samples 31, 39 and 51 in grids C-3 and D-3. It is unclear whether these whole berries derive from fresh grapes or inflated raisins (Margaritis and Jones 2006). In sample 63, one whole 'pressed' grape skin is morphologically similar to the by-product of grape pressings.

Wild/weed taxa

These are rare in comparison to the substantial quantity of cereal grains and other cultivated crops present. The taxa recorded are typical of arable and ruderal habitats, including *Agrostemma githago, Avena fatua, Chenopodium* sp., *Fumaria* sp., *Galium* sp., *Medicago* sp., *Malva* sp., *Papaver* sp., *Polygonum convolvulus*, Rubiaceae, *Silene* sp. and *Vicia* sp.. These are all annual species with early/intermediate flowering onset periods, suggesting that they could have been in seed when crops were harvested. Many of these weeds are large-seeded/equivalent to grain size, or remain in heads (e.g. *Malva* sp.) during processing (cf. Jones 1987).

4.2.4.3 STABLE CARBON ISOTOPE ANALYSIS

In total, 100 cereal grains (6-row hulled barley, free-threshing wheat, emmer wheat, rye) and 20 pulse seeds (broad beans) were selected for stable carbon isotope analysis. The cereal grains and pulse seeds come from a range of different samples taken throughout the mid-14th century destruction/conflagration deposit in Trenches B and Z, to increase the probability that the plant remains derive from different plants, fields and/or years. Though the destruction/conflagration deposit is a primary context, it is important to emphasise the plant remains present within the structure when it was destroyed by fire were not necessarily deposited in one episode. The cereals could therefore reflect a mixture of harvests from several years. Mean $\Delta^{13}C$ values are presented in Table 4.17 and box plots of the results are presented in Figure 4.26. The results for each sample individually are presented in Appendix 11.

The mean $\Delta^{13}C$ value for 6-row hulled barley is 17.8 ± 1.0‰, with 46% (23/50) of samples falling within the 'moderately watered' band (17-18.5‰) defined by Wallace et al. (2013). Samples within this range are difficult to interpret since they could reflect a mixture of rainfed or irrigated cultivation, though 24% (12/50) of the samples have $\Delta^{13}C$ values <17% (i.e. poorly watered/rainfed), whilst 30% (15/50) of the samples have $\Delta^{13}C$ values >18.5% (i.e. well-watered/irrigated). The total range of $\Delta^{13}C$ values is 15.1-19.4‰. This wide range may indicate that the hulled barley grains were cultivated under a range of different conditions. Support for this interpretation is provided by comparing the results to the minimum/maximum $\Delta^{13}C$ values recorded for modern rainfed and irrigated hulled barley (see Chapter 2, Table 2.5 and Figure 2.2). For modern rainfed barley, the maximum recorded $\Delta^{13}C$ value is 19.2‰, however, 95% of modern grains have $\Delta^{13}C$ values which are <18.5‰. In comparison, for modern irrigated hulled barley, the minimum recorded $\Delta^{13}C$ value is 16.6‰, however, 97% of grains have $\Delta^{13}C$ values which are >18‰. The archaeological samples have $\Delta^{13}C$ values which are significantly *higher* the typical maximum range for rainfed crops (>18.5‰) as well as samples which are significantly *lower* than the typical minimum range for irrigated crops (<18%). This would suggest a mixture of both rainfed and irrigated hulled barley grains are present, from different fields.

Free-threshing wheat grain $\Delta^{13}C$ values also range widely, 14.6-19.1‰, with a mean $\Delta^{13}C$ value of 17.0 ± 1.2‰. A small sample of emmer wheat grains (*n*=5) have a similar mean $\Delta^{13}C$ value, 17.0 ± 0.8‰. Overall, 54% (19/35) of the samples are within the typical range for an irrigated crop (>17‰), equivalent to the 'well-watered' band defined by Wallace et al. (2013). In comparison, 31% (11/35) of the samples fall within the more conservative 'well-watered' band defined by Flohr et al. (2019). It is notable that four samples have very high $\Delta^{13}C$ values (>18‰), beyond the maximum range currently recorded for rainfed cultivation (see Chapter 2, Table 2.5 and Figure 2.2). As with hulled barley, the wide range of free-threshing wheat grain $\Delta^{13}C$ values likely indicate a mixture of rainfed and irrigated free-threshing wheat grains are present. Rye grain $\Delta^{13}C$ values also range widely, 15.2-20.1‰, with a mean $\Delta^{13}C$ value of 17.0 ± 1.5‰. The rye grains fall primarily within the range recorded by Kottmann et al. (2014) for 'severe drought' (<18‰), though as already noted this needs to be clarified through further research.

In comparison to the range of 'rainfed' and 'irrigated' $\Delta^{13}C$ values for cereal grains, the broad bean samples clearly stand out as a 'well-watered' or irrigated crop. The mean $\Delta^{13}C$ value is 18.4 ± 1.0‰, and 90% (18/20) of the samples have $\Delta^{13}C$ values >17‰. This is comparable to the mean $\Delta^{13}C$ values for modern irrigated broad beans in south-eastern Spain (16.7‰, 16.0-17.9‰: Araus et al. 1997a) and Greece (17.7 ± 1.5‰: Wallace et al. 2013). Similarly, Bogaard et al. (2018) recorded a mean $\Delta^{13}C$ value of 18.6 ± 0.2‰ for broad beans cultivated in an area of high rainfall in northern Morocco. The cultivation of broad beans around Bulbuente is today restricted to irrigated market-gardens (*huertos*) since they cannot feasibly be grown on large-scale without irrigation.

4.2.4.4 OVERVIEW

Sample composition and formation

The samples from the conflagration/destruction deposit appear to primarily reflect the remains of stored free-threshing wheats, hulled barley and rye. The crop remains in the burnt occupation layers (H104, B57, Z22) below the conflagration deposit probably reflect stored crops falling from containers or areas above, possibly in addition to any other crop items present. The highest density of cereal grains (and other plant remains) are in samples from Trench B. This could reflect crops stored up against the wall, or a natural preservation bias created by debris falling from the wall restricting the supply of oxygen. The overall density of cereal grains within the deposit is not particularly high and other examples of studied granaries destroyed by fire have produced thick grain-rich deposits, comprising several hundred or several thousand items/L (e.g. Ruas 2002; Ruas et al. 2005a). However, it is important to note that only a small area of the burnt structure has been excavated and it is possible that grain-rich deposits could be present in other areas.

Several different sources of plant remains have probably become mixed together when the structure burnt down, particularly if crops were stored on a first storey. The grid-squares contain strikingly similar proportions of free-threshing wheat, hulled barley and rye; it is unlikely that this has happened purely by chance. However, it cannot be established whether the different cereal species were stored separately in similar quantities in close proximity to one another, subsequently becoming mixed in the conflagration. Or alternatively, whether the different cereals had already been deliberately mixed together in storage. The lower numbers of other charred plant remains present could reflect minor crop contaminants, particularly in the case of oat, emmer/einkorn wheat, flax and pulse seeds which resemble the cereal grains in growth pattern and/or seed size (Jones and Halstead 1995). However, minor crop contaminants are unlikely to explain the occurrence of large fruit stones (e.g. peaches) and nutshells (e.g. walnuts).

As already outlined in reference the conflagration deposit at La Mora Encantada, it is necessary to consider that *any* plant remains present within the structure could have become charred. Whilst the majority of plant remains present probably derived from the storage of cereal grains, associated weeds and potential crop contaminants, it is clear that plants from other sources have also become charred within the structure. This could potentially include discarded food items, residues from previous crops or plants introduced by wild animals. It is not unreasonable to suggest that the low numbers of fruitstones/nutshells from olives, peaches, sweet cherry, figs and walnuts could have been introduced by wild animals (birds, rodents) inhabiting the building. In the case of chaff and wild/weed taxa, some of these could derive from flooring/roofing, or material incorporated into the production of adobes[7] (cf. Delgado and Guerrero 2006; Henn et al. 2015). Within the dry confines of the building, plants from several different origins could potentially survive for decades or even longer, only becoming charred when the structure burnt down (cf. Ernst and Jacomet 2006). Plants may also have been introduced by stalling animals within the building as suggested by the low numbers of charred sheep/goat dung pellets in samples 38 and 50.

Crop-processing and arable weeds

The assemblage is dominated by cereal grains suggesting a cleaned store crop which has undergone coarse-sieving and fine-sieving to remove contaminants including chaff and weeds (Table 4.18; Figure 4.27). The cereal grains probably reflect prime grain based on their large size and the comparatively low numbers of runt/tail-grains. A small number of large-seeded weed seeds (e.g. *Agrostemma githago, Galium aparine, Polygonum convolvulus*), or headed-weeds (e.g. segments of *Malva* sp. flowerheads), are likely to have been retained with the coarse-sieve product (Jones 1984, 1987). The presence of small-seed weed species could derive from earlier crop processing stages, or material which has not been removed during fine-sieving. All of the wild/weed taxa recorded are probably all arable weeds, though the samples are all classified as ‘mixed’ due the presence of non-cereal crops (e.g. millets, fruits/nuts, pulses) and the

[7] Four small fragments of charred adobes were disaggregated in water and were found to contain only flecks of charcoal/charred plant remains. See note 1, for the same conclusion.

combination of different cereal species (see Chapter 2, section 2.2.2). Consequently, some of the weeds could equally derive from other cultivated crops such as millets or pulses.

Although the assemblage is dominated by cleaned cereal grains, material from earlier crop processing stages may also be present in some samples containing large numbers of rachises, particularly for rye (Table 4.18). It would not be unusual for by-products of crop processing to be stored alongside cleaned cereal grains. For instance, in his ethnographic research, Hillman (1985) observed pots containing cleaned cereal grains and crop-processing by-products could be found alongside one another in storerooms. In Grid C-3, the partial remains of rye straw may be present (accounting the for the large number of rye rachises). Rye has traditionally been valued for is straw since it produces tall, tough stems suited to purposes such as thatching or binding cereal sheathes (Halstead 2014:78, 96, 139).

4.2.4.5 SUMMARY OF THE ARCHAEOBOTANICAL AND CROP STABLE CARBON ISOTOPE EVIDENCE

- The samples produced a large, well-preserved archaeobotanical assemblage dating to the later medieval period (mid-14th century).

- The samples come from a destruction/conflagration deposit and contain abundant cereal grains, alongside other material, which has become mixed together when the structure collapsed. The rarity of chaff and weed seeds is indicative of a (semi-) cleaned grain product. However, the density of cereal grains within the deposit is not especially high (<100 items/L), as would be expected in a fully stocked granary destroyed by fire.

- Rye, hulled barley and free-threshing wheat dominate the archaeobotanical assemblage, occurring in near-identical proportions within all the areas sampled. Both bread wheat and durum wheat are confirmed by the presence of diagnostic rachises. 6-row hulled barley is indicated by asymmetric grains and diagnostic rachises, though 2-row hulled barley cannot be excluded. Large oat grains are also common and these are probably from the cultivated species, though no diagnostic floret bases were recovered. There is little evidence for other cereal species, including emmer wheat and possible einkorn wheat grains.

- Other crops identified include millets (broomcorn millet, foxtail millet), pulses (pea, broad bean, lentils, bitter vetch) and flax. Fruits/nuts are relatively common, including olive, blackberry, grape, fig, mulberry, possible plum, peach, almond, sweet cherry, walnut and hazelnut. One probable pressed grape skin has also been identified.

- Remains of wild/weed taxa are rare, as expected for a (semi-) cleaned grain product. The few species present are typical of arable and ruderal habitats, though specific weeds cannot be associated with crops.

- The crop stable carbon isotope evidence suggests that the free-threshing wheat and hulled barley grains are from different fields and/or different years. This inference is based on the very wide spread of $\Delta^{13}C$ values observed, which includes samples within the ranges expected for both rainfed and irrigated crops. Rye may have been cultivated in rainfed fields. In comparison, there is less variation in the broad bean $\Delta^{13}C$ values, which clearly reflect an irrigated crop.

4.2.5 Castillo de Grisel, Grisel (later medieval, 14th century)

The castle at Grisel is a small fortification situated on a rock outcrop (625m a.s.l.) within the village of Grisel (Figure 4.28). The area around the site forms the lower slopes of the Sierra del Moncayo. The castle dates from the 12th century, with the earliest phase of construction corresponding to a fortified stone tower, though much of the present-day structure dates from the 14th-15th centuries (Gutiérrez 2005). Small-scale excavations were undertaken during the restoration of the castle in 1988-1991 (Gutiérrez and Gerrard 1992).

The features identified during the restoration works included two large, plaster-lined rectangular tanks (Figure 4.29). The form of these tanks suggests that they were originally designed to retain a liquid (possibly grape pressings), though their original function is unclear. The tanks were truncated by the construction of a 14th-15th century perimeter wall and one tank (Tank 1) was deliberately infilled at this date. This feature contained a secondary, or probably tertiary deposit (1003, 1004), rich in refuse-type material (faunal remains, pottery etc.). Pottery recovered from the fills dated to the 14th century. Bulk-samples taken during the excavation were retained and selected for analysis as part of this PhD research.

4.2.5.1 SAMPLING

Overall, 2 samples were collected, with a total sample volume of 122L (Table 4.19). The upper (1003) and lower (1004) fills of the tank were 100% sampled.

4.2.5.2 ARCHAEOBOTANICAL EVIDENCE

The archaeobotanical results are summarised in Table 4.20, with the full dataset in Appendix 12. The two samples analysed produced a small assemblage of plant remains, with 86 charred and 4 mineralised plant remains identified. The flots are moderate in size (150-220ml), with varying quantities of charcoal and plant remains. The density of plant remains is low in both samples, 0.3 items/L in sample 1 and 2 items/L in sample 2. The charred plant remains comprise cereal grains, chaff, flax, millets, pulses, fruit/nut remains and wild/weed taxa. The level of preservation is variable. The low numbers of mineralised remains include indeterminate fragments, grape pips and a fig nutlet.

Crops

The cereal grains identified range from poorly preserved to near-perfect. The species include large (>2mm) oat, free-threshing wheat and hulled barley. Two of the hulled barley grains are asymmetric, indicating the presence of 6-row hulled barley. Runt/tail grains of hulled barley are also present. Chaff remains comprise indeterminate rachis fragments and two free-threshing wheat rachises. Millets are represented by three grains of broomcorn millet, whilst the only identifiable pulse seed is a pea. Sample 2 produced a small assemblage of poorly preserved flax seeds, comprising 20 whole seeds, 5 fragments and a further 5 probable fragments. No flax capsule fragments are present. Fruit/nut remains include indeterminate fleshy fruit fragments, indeterminate fruitstone/nutshell fragments, fig nutlets, walnut shell, grape pips, a whole grape berry and grape berry fragments. The mineralised remains also include grape pips and a fig nutlet.

Wild/weed taxa

Low numbers of wild/weed taxa are present including *Agrostemma githago*, *Chenopodium* sp., Poaceae spp., *Rumex* sp., *Thalictrum* cf. *flavum* and *Vicia* sp. Whilst *Agrostemma githago* is a character species of the phytosociological Secalinetea class associated with (rainfed) winter cereal fields (Braun-Blanquet and de Bolós 1957), *Thalictrum* cf. *flavum* tolerates/prefers damp habitats (e.g. streamsides) and it is unlikely to be weed of cereal cultivation since it has a late flowering onset period (July-September).

4.2.5.3 OVERVIEW

The fills of the tank may be characterised as secondary or tertiary deposits, containing a mixture of refuse from several sources. Some of this material is likely to derive from crop-processing debris based on the presence of chaff and cereal grains, including runt/tail-grains which may reflect the coarse sieving by-products (cf. Hillman 1985). The assemblage of flax seeds is more difficult to explain, though the remains could conceivably derive from a single plant. The low numbers of mineralised plant remains suggest an organic-rich input (McCobb et al. 2003). Since fig nutlets and grape pips are ingested with the fruit this could reflect the inclusion of some (redeposited?) cess/latrine waste.

4.2.5.4 SUMMARY OF THE ARCHAEOBOTANICAL EVIDENCE

- The samples produced a small, though diverse assemblage of plant remains including both charred and mineralised remains dating to the later medieval period (14th century).

- The tank contained a secondary or tertiary deposit of refuse and the archaeobotanical assemblage reflects this. The charred assemblage probably incorporates crop-processing debris and refuse, whilst the mineralised remains may indicate an element of cess/latrine waste.

- The crops recorded include cereals (free-threshing wheat, hulled barley, possibly oat), broomcorn millet, pea, flax and fruits/nuts (grape, fig, walnut). Considering the small quantity of charred plant remains present, flax is particularly frequent. Low numbers of mineralised grape pips are present.

- The wild/weed taxa present include arable and ruderal weeds, some of which are likely to be associated with crop-processing debris.

4.2.6 Casa Conventual de Ambel, Ambel (later medieval, 15th century)

The Casa Conventual, or preceptory, is a multi-period building complex adjacent to the church of San Miguel, within the village of Ambel (Figure 4.30; see above). The earliest structure at the site is a probable Islamic fortified tower, around which a 12^{th}-13^{th} century building complex was constructed by the Templars (Gerrard 2003). In the 14th century, the site passed to the Hospitallers and over several centuries it has been extensively remodelled. From 1993 to 1995, small-scale excavations were undertaken within the building complex (Gerrard and Gutiérrez 1995).

The 1993 excavation season targeted a very large, bell-shaped rock-cut pit (c.3m deep), probably a silo or water-cistern (Gerrard 2003; cf. Blanco Morte 2007). This feature may originally have been constructed during the Islamic period, however, it was deliberately infilled in later centuries, predominantly between the 15th-17th. Bulk-sampling was undertaken during the excavation and a small quantity of archaeobotanical evidence was recovered from the upper fills (Straker in

Gerrard 2003). Unprocessed bulk-samples collected from the lower fills of the feature had been retained and samples from four contexts were selected for analysis as part of this PhD project. The samples derive from secondary or tertiary deposits containing a mixture of refuse and building rubble. Pottery associated with the samples suggests that the deposits date to the 15th century.

4.2.6.1 SAMPLING

Overall, four samples were collected, with a total sample volume of 375L (Table 4.21). A 100% sampling strategy was adopted on-site, with later sub-sampling during processing.

4.2.6.2 ARCHAEOBOTANICAL EVIDENCE

The archaeobotanical results are summarised in Table 4.22, with the full dataset in Appendix 13. The four samples analysed produced a very small assemblage of plant remains, with 36 charred and 3 mineralised remains identified. The flots are small (80-160ml). The density of plant remains is very low, <0.1-0.2 items/L, in all the samples. The level of preservation is variable, though the preservation of charcoal and charred plant remains is notably better in sample 4. The charred plant remains include cereal grains, chaff, millet, pulses, fruits/nuts, flax and wild/weed taxa. Other charred non-plant remains include a textile fragment in sample 1.

Crops

The cereal remains present include grains of hulled barley, rye and wheat, indeterminate grains/fragments and one cereal-sized culm node. One millet grain can be identified as broomcorn millet. The pulses present include one well-preserved pea and one unidentified fragment, comparable in size to a pea or bean. Two well-preserved flax seeds are present in samples 1 and 4. Remains of fruits/nuts are comparatively frequent by comparison to the other charred plant remains present. This includes one large (>10mm) walnut shell fragment, one olive fruitstone fragment, grape pips (and fragments), a whole charred grape berry and numerous grape berry fragments. Mineralised grape pips are present in sample 4.

Wild/weed taxa

No identifiable remains of wild/weed taxa are present in the samples.

4.2.6.3 OVERVIEW

Sample composition and formation

The small quantity of charred and mineralised plant remains present probably reflect a mixture of material from several sources. The very low densities of remains are indicative of background settlement 'noise', probably incorporated alongside other domestic refuse and rubble when the feature was infilled from the 15th century onwards. The mineralised grape pips could indicate the inclusion of some cess/latrine waste. Although cereals (and other products) were stored in granaries at the site, crop-processing activities probably took place elsewhere which may partly explain the rarity of charred plant remains.

4.2.6.4 SUMMARY OF THE ARCHAEOBOTANICAL EVIDENCE

- The samples produced a small archaeobotanical assemblage and an extremely low density of charred/mineralised plant remains dating the later medieval period (15th century).

- The assemblage probably reflects a mixture of background settlement 'noise', refuse and possibly an element of cess/latrine waste (based on the presence of mineralised remains).

- The crops identified include cereals (wheat, hulled barley and rye), broomcorn millet, flax, pea and fruits/nuts (grape, fig, walnut, olive). Low numbers of mineralised grape pips are present. No remains of wild/weed taxa are present.

4.3 Discussion

The final section of this chapter brings the archaeobotanical and crop isotope evidence together from all the sites studied in the Huecha Valley to examine diachronic changes between the early medieval, Islamic and later medieval periods. The evidence is discussed within a local context, and for the later medieval period it is compared against documentary sources and archaeological evidence.

Due to the arrival of the Cistercians and the Military Orders in the 12th century, there is a large body of documentary evidence for the later medieval period, whereas none exist for the early medieval or Islamic periods. These landowners had a vested interest in the organisation of agriculture, and consequently many of the sources are concerned with sales of land, irrigation and the collection of rents/tithes. It is beyond the scope of this PhD to undertake an in-depth review of these sources, which would require new archival research, however several studies have compiled and analysed the surviving documentary sources (e.g. Corral Lafuente and Escribano Sánchez 1980; Corral Lafuente 1981; Ainaga Andrés 1987; Forey 1988; Gerrard 2003, 2011; Rodríguez Lajusticia 2010, 2014).

Whilst these documentary sources provide valuable information, it is important to be aware of their limitations. Firstly, there are unsurprisingly more sources for later centuries, with few providing detailed information for the 12th and 13th centuries (i.e. the two centuries after the Christian conquest). Secondly, the sources are biased towards the most important crops in the collection of rent/tithes, namely cereals, vines, olives, flax and hemp. In comparison, cultivation that needed no recording for tax purposes (e.g. vegetables for family consumption) are almost totally absent from the records. There is a general bias towards the priorities of the landowners, and consequently this has skewed the relative importance of different crops.

The terminology used in historic sources can also pose some challenges. There are often only generic references to fruits, pulses or the produce from *huertos*, particularly for earlier periods. Similarly, generic terms are used to refer to crops and it is unclear in some cases which species is being referred to. For example, whilst some sources simply refer to 'wheat', others include references to both *trigo candeal* (durum wheat) and *trigo* (?bread wheat). *Trigo candeal* is normally thought to be durum wheat, however, the term may also have been used to refer to bread wheat. Similarly, it is unclear whether the designation *trigo* solely refers to bread wheat or potentially a mixture of different free-threshing wheat species. Finally, little information is also provided about crop husbandry practices, with only occasional references to specific produce from the irrigated *huertas* or *huertos* in later centuries (e.g. Gerrard and Gutiérrez 2003b:89).

Despite these limitations, the archaeobotanical and documentary evidence provide different kinds of information. A major strength of the documentary sources is that they provide information on aspects such as the management of irrigation systems or the collection of rents/tithes which are difficult to identify archaeologically. On occasions, the geographical location of certain crops is also given, mentioning field-names or areas that still exist today. In comparison, archaeobotanical evidence provides a record of aspects not touched upon in the documentary sources such as 'missing' crops or cultivation practices. By interweaving the archaeobotanical evidence with information from documentary sources and archaeological studies, it is possible to provide a more holistic understanding of changes in agriculture.

4.3.1 Cereals

From the early medieval to later medieval period, two cereal species dominate the archaeobotanical record: hulled barley and free-threshing wheats. In the early medieval period at Bureta, the only free-threshing wheat species identified is bread wheat, with 34 rachis segments recorded in multiple samples/contexts. The crop isotope evidence suggests that the corresponding grains (probably all bread wheat) were cultivated under rainfed conditions. Whether durum wheat was genuinely absent, or simply not recovered, is unclear. Durum wheat has previously been recorded in other early medieval settlements in Iberia (Sopelana 2012; Vigil-Escalera Guirado et al. 2014) and it was probably also present in the Roman period (Alonso 2005), although the relative importance of these two wheat species is unclear (Peña-Chocarro et al. 2019; see Chapter 5). Further samples from a larger excavated area would be required to test whether durum wheat was actually absent in the early medieval period across the Huecha Valley.

By the Islamic period, both durum wheat and bread wheat are clearly present at La Mora Encantada. A large number of well-preserved rachises from both species were recorded in similar proportions. Provided that this does reflect a change in crop husbandry, the introduction of durum wheat may reflect a shift in culinary and cooking traditions. Traditionally, durum wheat has been used to produce products such as coarse breads, flatbreads, pastas, couscous, frikké and bulgur, whilst bread wheat (as its name suggests) was used to produce a finer type of bread (Hillman 1985; Alonso et al. 2014b). The 10th century Calendar of Córdoba refers to the harvesting of *farīk* (green durum wheat), probably freekeh (Pellat 1960). The two crops may also be combined together to produce a coarse bread, comparable to those traditionally consumed throughout the Mediterranean (Bolens 1980; Hillman 1985). The crop isotope evidence indicates that both bread wheat and durum wheat were irrigated, potentially being cultivated under the same conditions. These two crops can be cultivated together (Halstead 2014:68). Free-threshing wheats, especially bread wheats, are thought to be a more drought-sensitive and demanding crop than hulled barley (e.g. Riehl 2009). It is interesting to note that the isotopic evidence points towards the rainfed cultivation of hulled barley (see below). However, it should be noted that traditional landraces of bread wheat are better adapted to growing in more marginal conditions (i.e. lower water and nutrient availability) than modern varieties (Bogaard 2016). The preferential irrigation of free-threshing wheats potentially reflects a cultural preference, and 'wheats'[8] are

[8]It is often unclear which wheats are being referred to in these sources, though in most cases it is thought that they are referring to the free-threshing wheats (Hernández Bermejo et al. 2012).

thought to have been the most widely consumed cereal in al-Andalus (Bolens 1980; García Sánchez 1996; Hernández Bermejo et al. 2012).

In the later medieval period, both durum wheat and bread wheat are also recorded at Palacio de Bulbuente. The crop isotope evidence suggests that the assemblage includes grains harvested from different fields/years, with cultivation in both rainfed and irrigated areas. It is unclear whether bread wheat and durum wheat were cultivated together, or under the same conditions, since too few rachis segments were available for isotope analysis. Free-threshing wheat was also recorded at Castillo de Grisel.

Documentary references to wheat are common from the 12th century onwards, though it is often unclear which wheat species is being referred to (Rodríguez Lajusticia 2010). However, in the 14th century tithes provided to the Bishop of Tarazona included both *trigo candeal* (durum wheat) and *trigo* (?bread wheat) (Ainaga Andrés 1987). In this case, *trigo* appears to have been cultivated on a larger scale than durum wheat. At Ambel in 1380, *trigo candeal* is recorded as growing in the irrigated *huerta*, close to the *acequia* (Gerrard and Gutiérrez 2003b:89). Later sources from Ambel, and graffiti in the granaries, also refer to wheat with further references to its cultivation in the *huerta* (Gerrard and Gutiérrez 2003b:89-91; Gerrard 2003b:312). In neighbouring Tarazona, some wheat was cultivated beneath fruit trees in the 17th century (Ponsot 1971), a practice documented in other Mediterranean areas (cf. Forbes 1998; Hasltead 2014:205). Surplus wheat may have been treated as a cash-crop, and it was exported to neighbouring areas from the 12th to 13th century onwards, though this was prohibited at times of ecological stress due to grain shortages (Corral Lafuente 1983; Laliena Corbera 2008; Rodríguez Lajusticia 2019; cf. Halstead 2014:24).

In the 17th century, seven different wheat species/types are recorded as growing in Tarazona, in both rainfed areas and the irrigated *vega* (Ponsot 1971). In some cases, different wheat species/types are recorded as growing together (Ponsot 1971), presumably reflecting a mixture of durum and bread wheats. The cultivation of several different free-threshing wheat species/types appears to have been commonplace in north-east Spain until the 20th century (Verde et al. 1998; cf. Halstead 2014:233-288). It is highly probable that several different varieties of either bread wheat or durum wheat were cultivated throughout the medieval period. However, from an archaeobotanical perspective, the identification of free-threshing wheats typically does not go beyond the ploidy level (i.e. tetraploid durum-type wheats, hexaploid bread-type wheats). Some researchers have associated the presence of short/stubby free-threshing wheat grains with 'compact-type' wheats in the Iberian Peninsula (e.g. Alonso 2005; 2008;

Queiroz 2009). Similar short/stubby grains were recorded in the Islamic and later medieval assemblages analysed here and they occur alongside longer/thinner grains and intermediate forms (sensu Jacomet 2006). This variability in grain morphology could reflects different sub-species/landraces or alternatively within-ear variability, however, long intact rachises segments are required to accurately identify compact wheats (sensu stricto) (Jacomet 2006; cf. Maier 1996; Cappers 2012:316-317). With crop aDNA, it may eventually be possible to identify specific cereal landraces (Brown et al. 2015).

In comparison to free-threshing wheats, glume wheats (i.e. emmer, einkorn) are very rare. Only a single cf. emmer wheat glume base was identified in the early medieval period at Bureta, whilst no glume wheats were recorded in the Islamic period at La Mora Encantada. In comparison, by the later medieval period at Palacio de Bulbuente, emmer wheat and probably also einkorn are present, though they still form a minor component of the total assemblage. From the archaeobotanical evidence, it is clear that the scale of glume wheat cultivation was small, or alternatively that some of these remains could be contaminants of another crop (Jones and Halstead 1995). No references to either emmer or einkorn have been identified in documentary sources for the later medieval period and the archaeobotanical evidence thus provides a valuable record of their cultivation. No glume wheats are cultivated in the area today and they largely disappeared from cultivation across the Iberian Peninsula during the 20th century (Verde et al. 1998; Peña-Chocarro 1999). The small-scale cultivation of glume wheats may reflect their use to prepare specific foodstuffs (Hillman 1984b; Halstead 2014:284) or for the use of their straw, particularly in the case of einkorn (Peña-Chocarro et al. 2015).

Together with free-threshing wheats, barley was the most common species cultivated in all periods. In many cases, the grains were sufficiently well preserved to be identified as hulled barley. Only a handful of probable naked barley grains with a characteristic rounded cross-section and wrinkled surface are recorded. Naked barley is generally rare from the later prehistoric period onwards in western Europe (Buxó et al. 1997; Lister and Jones 2013), though it has been recorded in small quantities in Islamic and later medieval sites in north-east Spain (Alonso et al. 2014a). The low numbers of probable naked barley grains recorded are probably minor contaminants of the hulled barley crops. The 6-row hulled form is recorded from the early medieval to later medieval period, based on the presence of diagnostic rachises and asymmetric grains. The only secure identifications of the 2-row form are in the early medieval period at Bureta, though its presence at later sites cannot be excluded. Both 2-row and 6-row forms could have been cultivated together (Harlan 1978).

The crop isotope evidence suggests that in both the early medieval and Islamic periods hulled barley was cultivated under rainfed conditions. Hulled barley is considered to be the most drought tolerant of the cereals, with 2-row forms better adapted to drier conditions than 6-row forms (Helbaek 1960; Harlan 1978: 19-20; Charles 1984). Despite this, droughts may still have caused crop failures (cf. García Manrique 1960). In the later medieval period at Palacio de Bulbuente, the isotope evidence suggests a different picture with hulled barley cultivated under both rainfed and irrigated conditions. Irrigation can significantly increase the yields of hulled barley. For instance, at Aşvan in Turkey, Hillman (1973) noted that irrigation increased yields of traditional landraces of 2-row hulled barley (up to 6 times higher) and 6-row hulled barley (up to 12 times higher). Consequently, the cultivation of hulled barley in irrigated areas provided two benefits: it reduced the risk of crop failure and it could have significantly increased yields. Barley is widely referred to in documentary sources from the 12th century onwards (Rodríguez Lajusticia 2010), and at Ambel, 16th and 17th century sources refer to the cultivation of barley in the irrigated *huerta* (Gerrard and Gutiérrez 2003b).

Barley has traditionally been highly favoured as fodder, though it would be incorrect to assume that it was not also intended for human consumption, often being combined with free-threshing wheats to produce a coarse bread (Bolens 1980; García Marsilla 2013; Halstead 2014:68). Both crops could also have been cultivated together as a maslin, and as outlined earlier for the Teruel study area, this may have been a risk management strategy (Jones and Halstead 1995). In an inventory of items destroyed following a dispute between the Templars and Hospitallers in 1273 at Novillas, this wheat/barley maslin is referred to as *comuña*, and valued at a higher price than pure barley (Forey 1988). Interestingly, *comuña* is also recorded at Grisel in 1389 in payment of rent to the Bishop of Tarazona (Ainaga Andrés 1987:no.73). A further barley crop also recorded in documentary sources is *alcaceres*, a green barley hay harvested when immature (Gerrard and Gutiérrez 2003b:70; Coral Lafuente 1981:259). The 12th century agronomist Ibn al-ʻAwwām also refers to the cultivation of a green barley crop for fodder which was sown on irrigated land in May (Hernández Bermejo et al. 2012) and this practice is also attested ethnographically (Forbes 1998; Halstead 2014:27). It is interesting to note that barley is simultaneously referred to in the documentary sources as both *ordio* and *cebada*, with the latter possibly referring to *alcaceres*.

Rye is recorded at all the sites from the early medieval to later medieval period. In the early medieval period at Bureta it only forms a minor component of the total assemblage recovered, however, by the Islamic period at La Mora Encantada it is present in similar quantities to free-threshing wheats and hulled barley. In the later medieval period at Palacio de Bulbuente, it occurs in very similar proportions to both free-threshing wheats and hulled barley, indicating that it was a major crop. Documentary sources refer to rye from the 12th century onwards, though most references to cereals are to either barley or wheat (Rodríguez Lajusticia 2010). However, in tithes provided to the Bishop of Tarazona in the 14th century, rye was clearly a major crop at Añón, Los Fayos and Ambel, whilst other settlements in the Huecha Valley appear to have produced little rye (Ainaga Andrés 1987). The larger-scale of rye cultivation at Añón, Los Fayos and Ambel may in part be related to altitude since these villages would potentially have had access to fields in higher areas and rye is well-adapted to growing in cooler, mountainous environments (Hillman 1978; Halstead 2014:203). At Ambel, rye is mentioned from the 13th century onwards and it is also recorded as graffiti in the granaries (Gerrard and Gutiérrez 2003b; Gerrard 2003b). Traditionally, rye has been cultivated either as a monocrop or as a maslin with wheat (Hillman 1978; Latorre Ciria 2007).

One cereal species which clearly increases in importance in the later medieval period are oats. In the early medieval and Islamic period, oat grains are only recorded in low numbers and it is unclear whether these derive from the cultivated form (*Avena sativa*) or whether they are a weed (e.g. *Avena fatua*). In the later medieval assemblage at Palacio de Bulbuente, oat grains form a large proportion of the total grain assemblage. Although the diagnostic floret bases of common oat (*A. sativa*) were not identified, their frequency and the large size of the grains suggests that they are from the cultivated species. References to oats in documentary sources are less frequent than those to wheat or barley (Rodríguez Lajusticia 2010). However, oats were a major crop provided in tithes in the 14th century to the Bishop of Tarazona (Ainaga Andrés 1987). It is probable that oats were used as a source of animal fodder and given their tolerance for poor growing conditions, their cultivation may be linked to extensification.

The documentary sources for the later medieval period also provide a valuable insight into other aspects of the cereal economy. Firstly, there are numerous references to draught oxen throughout the later medieval period, and other draught animals (donkeys, horses) are also recorded (Forey 1988; Gerrard and Gutiérrez 2003a:51). An inventory of items/possessions destroyed in 1273 at Cabañas following a dispute between the Templars and Hospitallers is particularly insightful in this respect (Forey 1988). This inventory records ards/scratch ploughs (and associated components), plough parts (including iron coulters), yokes, draught oxen, sickles, a threshing sledge and numerous sieves, most likely for processing grain. Animal fodder is also recorded, including sacks of cereal bran. This inventory provides compelling evidence for an extensive form of agriculture involving draught oxen. Extensive cereal cultivation requires less labour input per unit area of land, potentially achieving a larger scale of cultivation and generating larger surpluses, yet a corollary of this is an increase in fodder requirements (Halstead 1995). This may be an important factor in explaining the increase in oat cultivation during the later medieval period. Draught oxen were no doubt present in the earlier early medieval and Islamic periods, although there is no direct evidence for this in the Huecha Valley. Oxen, ard points, plough coulters and other agricultural implements (i.e. yokes, mattocks/hoes, sickles) are documented elsewhere in al-Andalus (cf. Navarro Palazón and Robles Fernández 1996). In Córdoba, 10th century *fatwas* (legal documents) give the impression that oxen or draught cattle and seedcorn were shared out between farmers (Lagardère 1995; cf. Halstead 2014:51).

4.3.2 Millets

Millets (foxtail and broomcorn) were recorded at all the sites examined, though they were only present in low numbers relative to cereal grains during the early medieval period at Bureta. In comparison, by the Islamic and later medieval periods they are present in larger quantities, though it is difficult to gauge their importance relative to other cereals. The dominant species in all cases is broomcorn millet, with foxtail millet only forming a minor component of the assemblages. Both broomcorn and foxtail millet can be cultivated together and ethnographic research from north-west Spain supports this (Moreno-Larrazabal et al. 2015). Traditionally, millets have primarily been grown as a source of animal fodder, either being harvested at an immature green stage as a hay or as a fully mature crop (Halstead 2014:28). Grains from millets may also have been specifically fed to domestic fowl (Hernández Bermejo et al. 2012:199; cf. Alexander et al. 2019) although millets could also have been consumed and combined with other cereals to make bread (Gutiérrez Lloret 1991). Millets are no longer cultivated in the Huecha Valley, probably being replaced with the introduction of maize.

Though millets are a drought adapted crop, they typically require either high rainfall or irrigation due to their short summer growing season (Halstead 2014:28; Miller et al. 2016). A possible expansion in millet cultivation by the Islamic period may therefore reflect an increase in irrigated areas (cf. Miller 2011:66; Nesbitt et al. 2017:131). The Islamic agronomists Ibn Baṣṣāl (11th-12th century) and Ibn al-ʻAwwām (12th century) both state that broomcorn millet required irrigation (Hernández Bermejo et al. 2012:198). The earliest documentary reference to millet in the Huecha Valley is in 1179, when the monastery at Veruela was drawing up agreements over the allocation of water for irrigation with the neighbouring communities of Trasmoz, Trahit and Vera. The agreement stipulated:

"Veruela y Trasmoz tomarían el agua cinco días y cinco noches, y regarían sus mieses, en forma que Alfara no perdiese su zaiara. Recogidas las mieses, Veruela y Trahit ya no regarían, ni siquiera el mijo, sino con permisio de los hombres de Trasmoz." (González Palencia 1945:85-86)

[Veruela and Trasmoz will take water for five days and five nights and irrigate their cereal fields, with Alfara not losing its turn for watering. Once the cereal fields have been harvested, Veruela and Trahit will no longer irrigate, not even millet, without the permission of the people of Trasmoz]

This source implies that millet was normally irrigated. Throughout the later medieval period, millet is occasionally recorded in documentary sources, though it is simply referred to as *mijo* or *panizo* (Gerrard and Gutiérrez 2003b; Ainaga Andrés 1987; Rodríguez Lajusticia 2010). The translation of *mijo* or *panizo* is not straightforward, however. *Mijo* was potentially applied to different millet species, including broomcorn millet, foxtail millet and even sorghum; and *panizo* was applied to maize in later periods (Hernández Bermejo et al. 2012). Broomcorn millet with its short, summer growing period and tolerance of poor soils filled an important niche in agricultural systems, potentially as a catch-crop.

4.3.3 Pulses

Pulses form a minor component of all the archaeobotanical assemblages from the early medieval to later medieval period. Given the small quantities of pulse seeds identified, it is difficult to assess their relative importance in subsistence practices and diachronic changes in their use. In the early medieval period at Bureta, the pulses recorded include lentil, bitter vetch and grass pea. The same range of species are recorded in the Islamic period at La Mora Encantada, with the addition of pea. By the later medieval period, the species recorded include bitter vetch, pea and broad bean. The recovery of broad bean at Palacio de Bulbuente is of interest since these are large in size and comparable to the subspecies *Vicia faba* var. *major*. This larger-seeded broad bean may be a Roman or medieval introduction (Zohary et al. 2012:90). The isotope evidence clearly indicates that the broad beans were irrigated, most likely on a small, garden-scale in a *huerto*. Evidence for a weevil hole in one bean is indicative of a dried stored crop; low-level infestations such as these were often tolerated in crops intended for human consumption (Forbes 1998: note 5).

Later medieval documentary sources contain few references to pulses, presumably because they were cultivated on a smaller-scale than other crops and they were generally not supplied in rent/tithes, but for domestic consumption. Pulses have traditionally been viewed as a foodstuff of poorer classes (Valamoti et al. 2011), or as fodder crops in the case of bitter vetch and grass pea (Peña-Chocarro and Zapata Peña 1999; Halstead 2014:52-54). No documentary references to either bitter vetch or grass pea have been identified. The pulse species recorded in the documentary sources include chickpeas in the 13th century (Forey 1988) and broad beans a century later (Corral Lafuente 1981:461; Ainaga Andrés 1987; Rodríguez Lajusticia 2014). Corral Lafuente (1981:461) suggests that broad beans were one of the most important pulses cultivated in the area, and they were provided as tithes to the Bishop of Tarazona in the 14th century. Other sources indicate that dried broad beans were traded (Gaul 1976:311). At Ambel in the 16th and 17th centuries, documentary sources indicate that a range of pulses were cultivated in the irrigated *huertos*, including *arbellas* (peas), *alubias* (broad beans), lentils, chickpeas and New World beans (Gerrard and Gutiérrez 2003b). One further pulse recorded in the documentary sources is the fodder crop alfalfa. This is recorded at Ambel in the 16th and 17th centuries (Gerrard and Gutiérrez 2003b:70). Whilst no archaeobotanical evidence for alfalfa has been identified, seeds of *Medicago* sp. (which is in the same genus) were present at all the sites. Wild *Medicago* sp. could still have been provided as a fodder crop.

4.3.4 Oil/Fibre crops

Flax was recorded in all the sites examined. All the remains identified are seeds and no flax capsules have been identified, although these are less likely to be preserved than seeds in charred assemblages (cf. Valamoti 2011; Orendi in press). In the early medieval period at Bureta, only one flax seed was identified which is probably from the cultivated variety. Evidence for gold-of-pleasure was also identified at this site, and this is thought to be a weed of flax crops (Lataowa 1998; Alonso 2005). However, the gold-of-pleasure seeds are mineralised, suggesting that they were consumed (Alonso 2005). In the Islamic period at La Mora Encantada, a comparatively large number of flax seeds were recovered (n=68). Small quantities of flax seeds were also recovered at all of the later medieval sites examined, indicating its widespread cultivation.

The cultivation of flax, together with hemp, is widely recorded in documentary sources from the 13th century onwards (Corral Lafuente 1981:461; Ainaga Andrés 1987; Gerrard and Gutiérrez 2003b; Rodríguez Lajusticia 2014). Both were cultivated in the irrigated *huertas* as a fibre crop, and this continued up until the 19th century (García Manrique 1960). The production of flax or hemp fibres follow similar processes, with the removal of seed heads before retting (literally rotting) to breakdown the stems and this is then followed by breaking, which separates the ‘woody stems’ from the required fibres. Later medieval archaeological evidence for fibre production has been identified at Ambel, comprising retting tanks which are supplied with water from *acequias* and in 1514 a *molino trapero* (fulling mill) is also recorded there (Gerrard and

Gutiérrez 2003b:101). It is unclear whether earlier fulling mills existed in the Huecha Valley, though they were known in other areas (Utrilla Urtilla 1995; Navarro Espinach 2003a). Fibre production could also have been undertaken on a smaller-scale, with retting in small pools and stems broken by hand (Halstead 2014:140). By the later medieval period, both flax and hemp were important cash-crops and they were cultivated on a sufficient scale to be exported from Borja and surrounding towns (Rubio 2002; Monterde Albiac and Cabanes Pecourt 2000:545; cf. Falcón 1977). A small conglomeration of flax seeds at La Mora Encantada could reflect a crop which has been cleaned and processed for seed production (cf. Valamoti et al. 2011).

No archaeobotanical evidence for hemp was recovered which is surprising given the frequent remains of flax. This is unlikely to reflect a preservation bias caused by charring since experimental studies indicate that hemp seeds are more likely to survive charring than flax seeds (Märkle and Rösch 2008). A potential explanation is that some flax seeds were produced as a by-product of harvesting the plants for fibre, potentially with some flax also cultivated for seed production (Ertuğ 2000; Kislev et al. 2011). Flax seeds can be consumed, or alternatively they can be pressed to extract linseed oil. Traditionally, the seeds are roasted prior to consumption or oil extraction, increasing the probability of accidental charring (cf. Ertuğ 2000). Oil extraction involves grinding the roasted seeds (often using a mill stone) and then combining the product with water to form a dough which is then pressed to extract the oil. The resulting pressed dough, or linseed cake, was potentially a valuable source a fodder (Bond and Hunter 1987; Ertuğ 2000). Linseed oil has been used for a variety of purposes, including treatments for medical conditions, cooking, burning in lamps and as a preservative for materials such as rope and wood.

4.3.5 Fruits/nuts, vegetables and other crops

By far, the most common fruit recorded is grape, which was present at all the sites examined. In most cases, the evidence comprises charred pips/seeds and pedicles, alongside smaller numbers of mineralised pips/seeds. In addition, rarer evidence for whole charred berries and probable pressed grape skins were recorded in the Islamic and later medieval periods. In particular, in the Islamic period at La Mora Encantada, there is strong evidence to suggest that some of the grape remains are the by-product of grape pressings, which includes whole berries (and fragments), immature whole berries and 'pressed' skins. These remains are comparable to grape-pressings and they could be related to wine production, or the production of grape juices, vinegars, molasses or sweet pastes (cf. Marín 2003; Waines 2003; 2010:77). In the later medieval period, at Palacio de Bulbuente, a similar 'pressed' grape was also identified, alongside whole berries (and fragments). Berry fragments were also recorded at Castillo de Grisel and Casa Conventual de Ambel. All of these remains are potentially associated with wine production.

There are copious references to vineyards throughout the later medieval period, with the earliest sources dating to the 12th century (Gerrard and Gutiérrez 2003b; Ainaga Andrés 1987; Rodríguez Lajusticia 2010). Throughout the 13th century, vineyards feature prominently in the acquisitions of the monastery at Veruela (Rodríguez Lajusticia 2010:260-263) and a settlement charter issued to Villamayor in 1246 stated that 20 *nietros* of must (c.3000L) was to be provided to Veruela annually (Cabanes Pecourt 1984). Wine was also a priority for the Military Orders, and at Ambel the first reference to the Templars buying a vineyard is in 1162 (Gerrard and Gutiérrez 2003b:68). A later inventory from Ambel in 1289 recorded c.23, 000L of wine (Gerrard and Gutiérrez 2003b:51). An indication of the scale of cultivation is also provided in a document dating to 1273, which notes that c.43 000 vines were destroyed following a dispute between the Templars in Novillas and the Hospitallers in Cabañas (Forey 1988).

Evidence for olive is recorded between the early medieval to later medieval period, though in all cases the number of fruitstones recovered is low (n=<5). The rarity of olives in the archaeobotanical record is surprising given that olive groves are widely recorded in documentary sources throughout the later medieval period. In fact, this disparity between the documentary sources and archaeobotanical evidence may provide a clue to the use of the by-product from olive oil production, the press-cake. This press-cake is unlikely to have been discarded since it was potentially highly valued as fuel source (Rowan 2015), and also as a source of animal fodder (Foxhall 1998).

The importance of olive oil production is highlighted by documentary sources. For example, the monastery at Veruela was acquiring large numbers of olive groves from the 13th century onwards (Rodríguez Lajusticia 2010:257-260). At Ambel, an inventory from 1289 recorded 26 *arrobas* of oil (c.180kg) (Gerrard and Gutiérrez 2003b:51). Traditionally in the Huecha Valley, olives (together with vines) have been cultivated in areas on the periphery of the irrigated *huerta* due to their tolerance of thin soils and limited water availability (Gerrard 2011). It is interesting to note that olive cultivation appears to have been undertaken on a more widespread and intensive scale in the Huecha Valley compared to the neighbouring Queiles Valley (Corral Lafuente 1981:260-261). This difference in cultivation can be attributed to the different populations of these valleys; Muslims were predominant in the Queiles Valley, whereas Christians were more frequent in the Huecha Valley and olive cultivation was less heavily taxed (Corral Lafuente 1981:261; Wilkinson et al. 2005). This provides an interesting example of the factors which constrain and shape agricultural production.

With the exception of figs, evidence for other fruit/nut species is slight and probably reflects a preservation bias. Fruit/nut remains are typically underrepresented in charred assemblages, compared to waterlogged or mineralised assemblages (cf. Alonso et al. 2014a; Peña-Chocarro et al. 2014). Consequently, it is difficult to identify the introduction of new species and their relative importance. With the exception of grape and olive outlined above, there are few changes in the species recorded. In the early medieval period at Bureta, this included fig, mulberry, sweet cherry, peach and hazelnut. With the exception of peach and hazelnut, these species are all recorded in the Islamic period at La Mora Encantada alongside walnut. The largest diversity of fruit/nut species was recorded in the later medieval period, with fig, mulberry, ?plum, peach, almond, sweet cherry, hazelnut and walnut all recorded. The evidence for walnut from the Islamic period (none were recovered in the early medieval period) is of interest and walnut shell fragments were found in all the later medieval sites. It is likely that this expansion in walnut cultivation is coeval with an expansion in irrigation since the tree cannot easily cope with long, summer droughts (Djamali et al. 2010). In the Huecha Valley today, walnuts can be observed growing along the edges of *acequias* (personal observation).

Documentary sources for the later medieval period infrequently refer to the cultivation of fruit/nut species, and it is more typical to find references to *huertos*, fruit trees or simply just to trees. For example, in 1147 the monastery at Veruela acquired a *huerto* with trees (Rodríguez Lajusticia 2010:264). In 1273, hundreds of fruit trees (without specifying which species) are listed as property destroyed following a dispute between the Templars and Hospitallers (Forey 1988). A century later in neighbouring Tarazona, a more complete record of the range of species cultivated is provided. This includes cherries, peaches, ?apricot, plum, hazel nut, quince, apple, pear, walnut and fig (Corral Lafuente 1981:261). Provided that apricot is correctly translated in the documentary sources/correctly identifed, this is likely to be a new medieval introduction (Albertini 2013; Ruas et al. 2015; Peña-Chocarro et al. 2019). Mulberry is first recorded in documentary sources in the 17th centuries at Ambel (Gerrard and Gutiérrez 2003b:90; cf. Serrano Martín 1989:118). Interestingly, no documentary references have been identified to almond, a crop which is widely cultivated throughout the Huecha Valley today.

One group of plants largely absent from the archaeobotanical record are vegetables (excluding pulses) and other 'garden' crops (cf. Peña-Chocarro and Pérez Jordà 2019). Documentary sources from Ambel in the 16th and 17th centuries indicate that a range of vegetables and other crops were cultivated, including cabbage, cauliflower, onion, garlic, saffron, lettuce, *calabaza* (?bottle gourd) and cucumber (Gerrard and Gutiérrez 2003b:89-90). Other vegetables and crops may also have been cultivated which are not recorded in the documentary sources. It is possible that some the wild/weed taxa recorded in the archaeobotanical evidence were garden crops such purslane (*Portulaca oleracea*) and common vervain (*Verbena officinalis*).

4.4 Summary

The archaeobotanical record analysed here from the early medieval to later medieval period provides the first analysis of long-term changes in agriculture in the Huecha Valley. Overall, the pattern is one of broad continuity in the crop-spectrum between the periods, with small shifts in the range of crops cultivated and the relative importance of different crops. In particular, an increase in the scale of rye and broomcorn millet cultivation can be identified by the Islamic period, whilst oat increases from the later medieval period. More significant changes are apparent in the use of rainfed and irrigated areas, with an expansion in the use of irrigated areas for cereal cultivation through time. Changes in the organisation and management of agricultural spaces are highlighted by documentary sources and archaeological evidence for the later medieval period and these are hinted at in the archaeobotanical record. In particular, the increasing 'cerealisation' can be detected, accompanying the transition to a feudal regime following the feudal conquests. These changes are summarised by period below, and their wider implications are fleshed out in greater detail in the following chapter.

In the early medieval period, the crop spectrum is dominated by bread wheat and hulled barley, with both 2-row and 6-row forms cultivated. Rye is also present in small quantities and it is most likely a cultivated crop, opposed to a weed. On the basis of the small number of crop isotope samples, these cereals appear to have been cultivated in rainfed fields. Pulses form a minor component of the assemblage, and evidence for millets (foxtail and broomcorn) is equally rare. A diverse range of fruit/nut species are recorded, the most significant of these is grape, highlighting the importance of viticulture in this period.

A broad pattern of continuity in the range of crops cultivated can be identified into the Islamic period, although some new crops are added, whilst the importance of other crops changes. As in the preceding period, (6-row) hulled barley and free-threshing wheats are the dominant crops; however, in this case, there is evidence for both bread wheat and durum wheat, a new addition. Rye also increases in importance in this period, becoming a major component of the cereal assemblage. The crop isotope evidence provides a detailed picture of cultivation practices, with hulled barley (and probably rye) cultivated in rainfed conditions, whereas both bread wheat and durum wheat were cultivated in irrigated fields. There is also evidence for the increasing importance of broomcorn millet cultivation and this is probably linked to an expansion in irrigated areas. Pulses continue to form a minor component of the assemblage. Flax is well-represented in this period, and its presence is again likely to reflect an expansion in irrigation. The fruit/nut species present show a similarity to the preceding early medieval period, with the predominance of fig and grape. One new addition for this period is walnut and this could be linked to the development of irrigated arboriculture.

By the later medieval period, both (6-row) hulled barley and free-threshing wheat continue to remain the most important crops, although rye is now present on a par with these crops. The cultivation of both bread wheat and durum wheat can be confirmed for this period. Oat, most likely the cultivated species, is also present in larger quantities, whilst low numbers of emmer wheat and probably einkorn grains are also present. The crop isotope evidence from Palacio de Bulbuente suggests that cereal assemblage includes grains from several different fields and/or harvests, most likely reflecting the accumulation of grains through rent. Evidence for the cultivation of hulled barley and free-threshing wheats in *both* rainfed and irrigated fields is present, contrasting with the preceding Islamic period. It is suggested that these changes reflect the increasing importance of cereals in the economy, or 'cerealisation' (cf. Comet 2004), which accompanied the transition to a feudal system following the Christian 'conquests'. Other crops recorded for this period include broomcorn millet and pulses, especially broad bean. The fruit/nut species present again show similarity to the preceding Islamic period, with the addition of almond for the first time. However, the documentary sources point towards an increase in olive cultivation and, in particular, viticulture; neither of these changes are currently visible in the archaeobotanical record.

5 Discussion: regional and pan-regional perspectives

This chapter expands the discussion of the archaeobotanical and crop isotope evidence from the two study areas outlined in chapters 4 and 5. Revisiting the central tenet of this PhD, it assesses how the results fit into current debates surrounding the degree of continuity versus change in agriculture following the Islamic conquests. In particular, it revisits some of the questions outlined at the beginning of this research: what evidence is there for new crops and cultivars? Did innovation take place only in urban centres? What is the relationship between social status, faith and crops? Are there regional differences imposed by climate and geography? What evidence is there for changes in farming practices? Was dry-farming replaced by intensive irrigation-based agriculture and an increased importance of arboriculture and vegetable gardens? Were there major innovations following the Islamic conquests? Or alternatively, was Mediterranean agriculture characterised by longer-term continuity?

To address these questions, the results from this PhD are placed within a wider review archaeobotanical research from 164 Roman and medieval sites[9] in Iberia. This meta-analysis builds upon a previous synthesis by Peña-Chocarro et al. (2019)[10] who provide a comprehensive synthesis of previous archaeobotanical research. However, their study included data from many unpublished sites and the underlying dataset has not been made publicly available so the results are not reproducible (cf. Lodwick 2019). All of the available (published and unpublished) archaeobotanical from the original publications reviewed by Peña-Chocarro et al. (2019) has been re-examined on a site-by-site basis and updated to incorporate evidence from a larger number of sites and recently published studies, as well as charcoal evidence.

The archaeobotanical evidence identified through this review of published and unpublished evidence is first assessed at the regional scale, focusing broadly on the north-east of Iberia, with wider comparison made to other areas. For each period, the evidence from previous archaeobotanical studies and documentary sources is first outlined, and this is then compared with the results obtained from this PhD.

5.1 Archaeobotanical review methodology

Published and unpublished archaeobotanical data was compiled up to June 2019. Previous reviews of archaeobotanical evidence were consulted and where possible the original publication

[9] The term 'site' is used to refer to a specific occupation period i.e. distinguishing between Roman and early medieval evidence from a single excavation.
[10] This paper was published in 2017 and it identified evidence from 83 sites (98 in total accounting for multiple periods of occupation), of which 34 were unpublished (35%)

has been examined to ensure the accuracy of the dataset (Pinto da Silva 1988; Hopf 1991; Núñez 1988; Buxó 2005; Livarda 2008; Tereso et al. 2013; Peña-Chocarro et al. 2019). In many cases, the original archaeobotanical datasets are either unpublished or only presented as summary and consequently a fully quantitative review of the evidence has not been possible.

The archaeobotanical data gathered from these published and unpublished studies was recorded in a database, and the sites/data assigned into broad chronological periods: Roman, early medieval, medieval (Islamic), medieval (Christian), later medieval and post-medieval (i.e. post-15th century). The period classifications 'medieval (Islamic)' and 'medieval (Christian)' are used to refer to different geographical areas of Iberia under Islamic rule and Christian rule between the 8th and 12th centuries. The classification 'later medieval' is used to refer to sites dating after the 11th-12th centuries, specifically in areas conquered following the Christian conquests. Site locations (latitude/longitude) were recorded to the nearest identified area. Broad site type classifications are used and, where available, specific information on the feature(s)/context(s) sampled was also noted (silos, pits, ditches, wells, latrines (cesspits), ovens/hearths, general occupation deposits, burnt/conflagration deposits, shipwrecks and unknown). Dating evidence for the feature(s)/context(s) sampled was also recorded: associated finds/stratigraphy (i.e. pottery, small finds), radiocarbon dating of associated material (i.e. bone, charcoal) and direct (AMS) radiocarbon dating of plant remains. Only in exceptional cases have charred plant remains been directly AMS dated and most dating evidence comes either through phasing or pottery evidence.

Full references for both the site/excavation report and/or archaeobotanical data are provided where available. The archaeobotanical data was recorded on a presence/absence basis and the preservation type (charred, mineralised, waterlogged, desiccated, other/unknown, charcoal), recovery method, number of samples, sample volume, number of plant remains was also recorded. The dataset includes archaeobotanical data recovered systematically through bulk-sampling and flotation, as well as 'grab samples' and hand-recovered remains. The full dataset is presented in Appendices 13 and 14 and site locations are plotted in Figure 5.1. In the discussion below sites are referred to with the specific 'site number' and associated reference e.g. Lleida (Site 110: Alonso 2005) refers to the early medieval occupation period, whereas Lleida (Site 111: Alonso 2005) refers to the Islamic occupation period. References to the sites are provided in Appendix 13. Sites with unpublished data are also listed in Appendix 13 to note areas where research has been undertaken, although no archaeobotanical evidence has collated from these sites.

5.2 Overview of previous archaeobotanical research

In comparison to other areas of Iberia, a relatively large number of systematic archaeobotanical studies have been undertaken on Roman period sites in the north-east, though the evidence is overwhelmingly restricted to (urban) sites in Cataluña (Figure 5.1). In particular, key studies for the Roman period include those from the cities of Iesso (Site 89: Buxó et al. 2004) and Lleida (Sites 108-109: Alonso 2005) as well as the Roman and early medieval villa site of Vilauba (Sites 184-186: Colominas et al. 2017). Other key assemblages for the early medieval period include El Mallols (Site 75: Alonso et al. 2008) and l'Esquerda (Sites 106-107: Cubero et al. 2008). For the Islamic period, detailed studies have been undertaken in the cities of Lleida, Balaguer and Tortosa (Sites 111, 133, 177: Alonso et al. 2014a). To this list can be added a handful of evidence from other Roman, early medieval, Islamic and later medieval settlements in Cataluña. A notable absence in the current archaeobotanical dataset is evidence from later medieval urban sites.

Away from Cataluña, archaeobotanical studies are either very rare or non-existent in other areas. For example, in Aragón only one systematic archaeobotanical study has been undertaken on the Islamic settlement at Las Sillas (Site 105: Ros et al. press), whilst in La Rioja the only available evidence is from La Noguera where a preliminary archaeobotanical report has been published for the Roman and medieval (8th-15th centuries) periods (Sites 95-98: Peña-Chocarro et al. 2019). Similarly, further south along the Mediterranean coast in the region of Valencia, there are few published archaeobotanical studies and the majority of available evidence is restricted to charcoal studies on Islamic and later medieval sites. Consequently, the sites analysed for this PhD within the region of Aragón fill a clear gap in the current evidence.

5.3 Roman (1st-5th centuries) and early medieval period (5th-8th centuries)

Figure 5.2 shows the location of previous archaeobotanical studies undertaken on Roman and early medieval period sites in the north-east.

For the Roman period, the dominant cereals are (6-row) hulled barley and free-threshing wheat. At La Noguera (Site 96: Peña-Chocarro et al. 2019) bread wheat rachises have been identified, whilst at Lleida (Site 107: Alonso 2005) 'probable' durum wheat rachises are recorded. The relative importance of these two crops is unclear. Other cereal species (emmer wheat, oat, rye) form only a minor component of assemblages, and there is currently no evidence for either einkorn or spelt wheat. Rye is only recorded in very small quantities in this period at Lleida (Site 107: Alonso 2005) and in late Roman Vilauba, where it also occurs alongside oat (Site 182:

Colominas et al. 2017). Given the very limited evidence for rye, it was clearly a minor crop and potentially a weed of other cereals in these three sites at least (cf. Hillman 1978).

Millets have not been recorded for the Roman period, although they are present in small quantities during the Bronze Age and, in particular, the Iron Age when they become more widely cultivated (Alonso 2008; Alonso et al. 2008; Alonso and Bouby 2017). Their absence from the archaeobotanical record for the Roman period is therefore likely to reflect the paucity of archaeobotanical research undertaken to date. In either case however, it appears that that millets were not an important crop during the Roman period. Pulses have been identified in low numbers, including lentil, pea, broad bean, grass/red pea and vetch. One crop conspicuously absent for this period is flax, though it has been recorded in Roman settlements elsewhere in Iberia e.g. Castro de Orellán in Castilla and León (Site 56: López-Merino et al. 2010), and in Marroquíes Bajos (Site 115: Montes Moya 2014), Obulco, Jaén (Site 124: Stika et al. 2017).

A relatively diverse range of fruit/nut species are recorded for the Roman period. This can be partly attributed to waterlogged preservation in wells at Iesso, where hazel nut, fig, olive, stone pine, sweet cherry, plum, almond, blackthorn/sloe, peach, acorn, melon, blackberry, walnut and grape have been identified (Site 88: Buxó et al. 2004). Several of these species have also been recorded at other Roman sites in the north-east, with pomegranate also recorded in a charcoal assemblage at Lleida (Site 107: Piqué et al. 2012). By far the most common fruit/nut species for this period are fig, grape and olive, with these last two species overrepresented at sites where sampling and flotation have not been undertaken.

In the early medieval period, the crop spectrum is predominately characterised by continuity, with hulled barley and free-threshing wheats the most common cereal species. However, there are indications that free-threshing wheat was cultivated on a larger-scale than hulled barley at El Mallols (Site 75: Alonso 2008) and l'Esquerda (Site 106: Ollich et al. 2014). Similarly, at Vilauba, there is strong evidence for the cultivation of free-threshing wheat monocrops in both the late Roman and early medieval periods (Site 186: Colominas et al. 2017). At this site, weed assemblages associated with free-threshing wheat are interpreted as reflecting an extensive form of cultivation with low soil disturbance (Colominas et al. 2017).

Rye continues to remain rare in this period and forms a trace component of assemblages at El Bovalar (Site 73: Cubero 1990), El Mallols (Site 75: Alonso 2008) and l'Esquerda (Site 106: Ollich et al. 2014). An exception to this pattern is in Andorra at Camp Vermell (Site 31: Alonso et al. 2010) and Roc d'Enclar (Site 150: Buxó and González 1997), where rye is clearly a major crop. For example, at Roc d'Enclar, rye forms 22% (885/3939) of the total cereal assemblage. The mountainous and cooler climates where these sites are located probably accounts in part for the predominance of rye since it is well-adapted to growing in these environments (Hillman 1978; Halstead 2014:203). Oats are recorded at several sites, though it is unclear whether these are a cultivated species or a weed. At Vilauba, >3000 oat grains were present in a context containing c.60, 000 free-threshing wheat grains, however, the only diagnostic floret bases identified are from *Avena fatua* (Site 186: Colominas et al. 2017). Emmer wheat and naked barley are also recorded, though they form a minor component of assemblages e.g. El Mallols (Site 75: Alonso 2008). Millets, both broomcorn and foxtail, are also a minor crop in this period, except at l'Esquerda where broomcorn millet is comparatively abundant (Site 106: Ollich et al. 2014). At sites where millets are found in trace quantities, it needs to be questioned whether such remains are intrusive i.e. later contaminants (cf. Motuzaite-Matuzeviciute et al. 2013).

The pulse species present also show continuity with the previous Roman period, with lentil, grass/red pea, pea, bitter vetch, broad bean and vetches recorded. Flax has been identified at three sites, and at El Bolivar it is abundant with >18, 000 seeds identified, although no information is given on whether these remains derive from a single burnt cache (Site 73: Cubero 1990). The range of fruit/nut species recorded also show a similar pattern to the Roman period, with hazelnut, walnut, apple, olive, sweet cherry, fig and grape recorded. A probable melon seed has been identified in a waterlogged well at Foneira (Site 82: Ravotto et al. 2016), emphasising the potential preservation bias against fruit/nut remains in charred assemblages. One new fruit species is also recorded for this period: mulberry[11] at Vilauba (Site 186: Colominas et al. 2017).

The results of these previous archaeobotanical studies on Roman and early medieval sites in Iberia provide a valuable comparison to the evidence examined for this PhD in the early medieval settlement of Bureta (Table 5.1). This is currently the most intensively sampled early medieval settlement in north-east Iberia and it therefore provides a significant contribution to the current archaeobotanical dataset. Overall, the crop spectrum shows clear similarities to other sites, with hulled barley and free-threshing wheats dominating the assemblage. The excellent preservation of barley rachises indicates that both 6-row and 2-row hulled forms are present. In addition, it has been possible to securely identify the free-threshing wheat rachises as bread wheat. The data

[11] Mulberry at Vilauba is identified as black mulberry (*Morus nigra*), however, there is no reliable method for distinguishing the fruitstones from those of white mulberry (*Morus alba*). The fruits of both species can be consumed, though white mulberry is normally associated with silk production.

from Bureta provides the first diagnostic evidence for both 2-row hulled barley and bread wheat in the early medieval period.

The relative importance of the 6-row and 2-row forms of hulled barley is unclear, although 6-row hulled barley generally appears to be dominant. However, there is a bias towards the identification of 6-row forms which can (in general) be confirmed by the presence of asymmetric grains, whilst the identification of 2-row forms requires well-preserved rachis segments which are less likely to be recovered and identified (Bouby 2001; Jacomet 2006). Consequently, evidence for 2-row hulled barley is probably underrepresented. For example, Isidore of Seville writing in the 7th century, identifies both 6-row, *hexaticum*, and 2-row barley, *distichon* (Barney et al. 2006: 338), whilst in Mediterranean south-western France, the 2-row form has been identified sporadically in Roman and medieval settlements (Ros et al. 2014b; Ros and Ruas 2017).

Similarly, the relative importance of durum wheat or bread wheat during the Roman and early medieval periods is unclear since the diagnostic rachis segments have only been preserved from a small number of sites. Currently, the Roman city of Lleida is only site to have produced probable durum wheat rachises (Site 109: Alonso 2005), whilst bread wheat rachises have been recovered from the Roman settlements of La Noguera in La Rioja (Site 96: Peña-Chocarro et al. 2019), Obulco in Andalucía (Site 124: Voropaeva and Stika 2018) and Monte Mozinho in north Portugal (Site 120: Tereso et al. 2013a, 2013b). In the early medieval period, both bread and durum wheat have been identified at Gózquez in Madrid (Site 84: Vigil-Escalera Guirado et al. 2014) and at Zaballa in the Basque Country (Site 191: Sopelana 2012). Whilst both bread wheat and durum wheat have been recorded in Iberia since the Neolithic period (e.g. Antolín et al. 2014), different cultivars were probably introduced throughout prehistoric, Roman and medieval periods. Whether durum wheat was truly absent at Bureta needs to be examined through further excavation and sampling. Nevertheless, given the large number and volume of samples analysed (42 samples, 1134L), it would be expected that any remains of durum wheat would have been recovered.

Rye occurs in low numbers in several contexts at Bureta, and it is probably a cultivated crop rather than a weed. This is therefore an important record of rye cultivation during the early medieval period. In Iberia, the earliest securely dated remains of rye have been recovered from the Roman period at Monte (Site 122: Tereso et al. 2013a). The rarity of other cereals (emmer wheat, oat) and millets is paralleled at most other sites in the north-east. The limited evidence for pulses (lentil, grass/red pea, bitter vetch) at Bureta may reflect a preservation bias, and these species have all been recorded at other sites. Flax is also probably present, and gold-of-pleasure is also recorded for the first time in this period.

The fruit/nut species recorded also show a similar pattern to other sites, with grape and fig dominating the assemblage. The evidence for mulberry is of particular note since it has only been recorded at one other site, Vilauba (Site 186: Colominas et al. 2017), in the early medieval period. In addition, peach is also recorded for the first time in the early medieval period, although peach has previously already been identified in Roman settlements. Similarly, the evidence for coriander at Bureta is also the first record of this crop in either the Roman or early medieval period.

To summarise the key findings of archaeobotanical research undertaken on Roman and early medieval sites:

- Free-threshing wheats and (6-row) hulled barley are the dominant cereals in both periods, with slight evidence for glume wheats. Oats and rye are also rare in this period, although there are indications that rye becomes a more important crops in the transition between the Roman period and early medieval period. The archaeobotanical evidence from Bureta provides evidence for the cultivation of bread wheat, 2-row and 6-row hulled barley, possibly oat and rye. The assemblage provides evidence for the expansion of rye cultivation in the north-east, paralleling evidence from elsewhere in Iberia and Medieval Europe.

- Evidence for millets is comparatively slight. Millets are absent in the Roman period sites investigated to date, and in most cases millets (primarily foxtail millet) are present in trace quantities at early medieval sites. Broomcorn millet is, however, recorded in large quantities at a single early medieval site. Both foxtail and broomcorn millet are rare in comparison to cereals in the evidence analysed from Bureta.

- Flax is also absent in the Roman period sites investigated, although this may reflect a lack of archaeobotanical research, as opposed to its genuine absence. In the early medieval period, flax is recorded at a handful of sites, and one flax seed (probably the cultivated species) is recorded at Bureta, where evidence for gold-of-pleasure is also recorded.

- Pulses are poorly represented in archaeobotanical assemblages for both the Roman and early medieval periods. Despite this, a range of pulse species are recorded including pea, broad bean, lentil, bitter vetch, grass pea and vetch. Some of these species are also recorded at Bureta.

- A diverse range of fruit/nut species have been recorded in both the Roman and early medieval period, including hazel nut, fig, olive, stone pine, sweet cherry, plum, almond, blackthorn/sloe, peach, acorn, melon, blackberry, walnut and grape. Mulberry is added in the early medieval period. The archaeobotanical evidence from Bureta provides another early identification of mulberry in Iberia, together with coriander which is recorded for the first time in the early medieval period.

5.4 Islamic period (8th-12th centuries)

Figure 5.3 shows the location of previous archaeobotanical studies undertaken on Islamic period sites in the north-east.

For the Islamic period, the most detailed and comprehensive archaeobotanical studies undertaken to date are from the cities of Lleida, Balaguer and Tortosa in Cataluña (Sites 111, 133, 177: Alonso et al. 2014a). Here assemblages of charred and, in particular, mineralised remains have been recovered from 10th-12th century contexts. The cereal assemblages from these sites are dominated by 6-row hulled barley and free-threshing wheat, with bread wheat rachises identified at Pla d'Almatà. There is currently no evidence for durum wheat, although this could reflect an absence of diagnostic rachises rather than its actual absence. Rye has not been recorded, whilst evidence for other cereals (oat, emmer wheat) is sparse. Other crops are poorly represented, comprising foxtail millet, lentil, flax and gold-of-pleasure. The co-occurrence of flax and gold-of-pleasure is notable since this latter species is widely viewed as a weed of flax crops, and evidence for mineralised remains suggests that the crop was consumed (Alonso 2005). In comparison, fruit/nut species are abundant, primarily due the presence of cesspits/latrines with mineralised preservation. The species identified include cucumber/melon, walnut, apple, olive, pine nut, almond, peach, pomegranate and fig. By far the most abundant species are fig and grape. Evidence for spices/condiments has also been recovered in these mineralised assemblages, including celery, fennel and nigella.

At Tortosa, detailed research combining archaeobotanical, archaeological and documentary evidence provides further information on the cultivated areas (Virgili 2010, 2018; Kirchner et al. 2014; Puy et al. 2014; Kirchner and Virgili 2019). Here evidence for the drainage of wetlands has been identified during the Islamic period, and it is suggested that spring-sown 6-row hulled barley was cultivated in these areas. This interpretation is based on weed-rich samples with a predominance of spring germinating annual weeds, with long flowering periods and which flower late in the season (Kirchner et al. 2014; cf. Bogaard et al. 2001; Jones et al. 2005). Similarly, Kirchner et al. (2014) note the presence of the weed *Bolboschoenus* cf. *maritimus*, a species typical of poorly drained cereal fields (cf. Hillman 1991; Wollstonecroft et al. 2011). Other weeds recorded were more typical of extensive forms of cereal cultivation, with shorter and earlier flowering periods (e.g. *Avena fatua, Raphanus raphanistrum* subsp. *raphanistrum*). Analysis of documentary sources after the Christian conquest (c.12th century) indicates that irrigated *huertas*, olive groves and vineyards were common to the north of the city, whilst areas to the south were primarily characterised by *campus* and *terra*, probably reflecting field crops (e.g. cereals) and pasture (Virgili 2010; Kirchner et al. 2019). The documentary sources, however, provide little information on the range of crops cultivated, with only scant reference to *ordeum* (barley), *triticum* (wheat), *frumentum* (bread wheat?) and *bladum* (wheat?) (Virgili 2010). The term *bladum* could have referred to any grains used to make bread, only later becoming a synonym for wheat (Burns 1975:77; Commet 1992: 212-213). It is unclear whether durum wheat was also present.

Based on the documentary evidence, it is thought that the irrigated *huerta(s)* surrounding Tortosa were used primarily used for fruit trees and vegetables (Kirchner and Virgili 2019), though the possibility that cereal cultivation was also undertaken here should not be excluded (cf. Hernández Charro 2006: 322; Jiménez Puertas 2007:16; Martín Civantos 2011: 406). For example, in 17th century Tarazona, both cereals and fruit trees were cultivated together in irrigated *huertas* (Ponsot 1971). At other cities in the north-east, evidence for these irrigated *huertas* has also been identified such as in Tudela (Hernández Charro 2007) or Zaragoza (Ortega Ortega 2010), although their origin and development have not been examined in detail. The development of these (sub-)urban *huertas* is thought to be a key feature of the Islamic period across Iberia, however, dating their origins is problematic (Glick and Kirchner 2000:296; Martín Civantos 2018). The *huertas* span the rural/urban divide, and Kirchner (2019:86) highlights in the case of Valencia that the city was surrounded by networks of rural *alquerías* (farmsteads/hamlets).

Frustratingly, very little is known about the crops cultivated in these (sub-)urban *huertas* around cities beyond the examples of Lleida, Balaguer and Tortosa cited above since no archaeobotanical studies have been undertaken. In part, this reflects a lack of sampling, rather than a lack of excavation. Documentary references for the Islamic period only provide generic and sporadic references to irrigated areas and crops, especially fruits, in cities such as Barbastro, Calatayud, Daroca, Fraga, Huesca Monzón, Lleida, Tarragona, Tortosa, Tudela and Zaragoza (Table 5.3). For example, the 11th century geographer al-Udri remarked that Zaragoza was 'abundant in fruits' of 'immeasurable quality', whilst in Huesca there are references to apple, pear, medlar and service tree (Granja 1967:426; Cuchí Oterino 2005). At Tudela, al-Himyari notes the 'cereals of excellent quality' and the 'cultivation of fruit trees' (Martin Duque 1957). As highlighted above in the case of Tortosa, documentary sources generated after the Christian conquests can provide information on crops cultivated, although this information often takes the form of generic references to 'cereals', 'vineyards' and 'fruit trees' (Kirchner 2018:207).

Further south, the *huerta* of Valencia has been examined in greater detail and it is thought to have its origins in the Islamic period, although it was considerably modified and expanded after the Christian conquest in the 13th century (Torró 2009; Esquilache 2011; Kirchner 2018; Guinot Rodríguez 2019). Here post-conquest documents highlight a broader range of crops, including wheat, barley, rice, pulses (broad bean, pea, lentil), millet, sorghum, fig, carob, olive, grape, flax and vegetables (Guichard 2001:307; Parra Villaescusa 2013). Earlier sources from the Islamic period also refer to the cultivation of rice, sugarcane and citrus fruits in Valencia (Watson 1983; Butzer et al. 1985a); these crops are currently absent from the archaeobotanical record. Guichard (2000:81) has questioned whether 'new' crops such as rice in Valencia were important beyond the (sub-)urban irrigated *huerta* and this view is also echoed by others (Horden and Purcell 2000:259-260; Glick 2004). There are currently no published archaeobotanical studies from urban contexts in Valencia. However, recent stable isotope analyses of human remains (10th-13th century CE) from the Islamic period in Valencia provide some evidence for the crops cultivated, suggesting that C4 crops such as millets and/or sorghum were potentially an important component of diets (Alexander et al. 2019).

Shifting the focus to rural areas, very little archaeobotanical research has been undertaken on Islamic sites. Currently, one of the only systematically sampled sites is Las Sillas in the north of Aragón, although the total number of samples (n=13) and sample volume (95.5L) is still small (Site 105: Ros et al. in press). As a point of comparison with the sites analysed in this PhD, 9 samples were analysed at El Quemao with a volume of 644L, whilst at La Mora Encantada, 12 samples were analysed with a volume of 570L. The cereal assemblage from Las Sillas includes hulled barley, free-threshing wheat, oat and rye. It is clear that rye was an important crop here, and the frequency of oat grains suggests that they could derive from the cultivated species. No evidence for millets, pulses or flax has been identified, and only a small assemblage of fruit/nut remains was recorded including fig, olive, plum, hawthorn and grape. A small number of samples have also been analysed from silos at Melque (Site 118: Arnanz et al. 1999), where there was a very large assemblage of hulled barley (c.50 000 grains) and flax (c.28 000 seeds), alongside smaller quantities of free-threshing wheat and rye. A large assemblage of olive fruitstones were recovered in a separate feature, and a single grape/pip seed was also recovered.

Comparative evidence from other rural Islamic sites in the north-east is restricted to Tossal de Solibernat in Cataluña (Site 180: Cubero 1990), however, only a summary of the archaeobotanical evidence is published, with no information on the sampling methods. The assemblage from the site primarily comprised free-threshing wheat and hulled barley, with smaller quantities of naked barley, oat, rye and bitter vetch. At Zafranales, in the north of Aragón, a hand-picked grab sample included whole figs, peach fruitstones, olives and whole walnuts (Site 195: Montón Broto 1997). Evidence for walnut has also been recorded in a charcoal assemblage at Juslibol (Site 91: Alcolea Gracia et al. 2016). In the north of Valencia, the only rural Islamic site is Torre la Sal, where a small archaeobotanical assemblage was recovered, with evidence for hulled barley, fig, apple/pear and grape (Site 172: Pérez-Jordà 2010). Further south, at Castillo de Ambra, evidence for carob is recorded for the first time in a charcoal assemblage (Site 48: de Haro Pozo 2002).

Carob is not listed by Peña-Chocarro et al. (2019) as a crop in their review, however, it is a potential medieval re-introduction into al-Andalus, or it at least became more widely cultivated in this period (Carabaza Bravo 2004:206-209; Ramón-Laca and Mabberley 2004; Servera-Vives et al. 2018). There are currently no archaeobotanical finds of carob pods (fruits) or seeds, however, it is likely that the crop was specifically exploited for its pods/seeds and later medieval documentary sources record it as being cultivated and exported from Valencia (Guichard 2001:307; Soller Milla 2004, 2007). The pods and seeds of this tree have medicinal uses and they have been used to produce confectionery, although their primary use may have been as a source of animal fodder (Forbes 1998).

Comparing the results of these previous archaeobotanical studies with the evidence from the rural Islamic sites of La Mora Encantada, Cabezo de la Cisterna and El Quemao examined for this PhD reveals both similarities and differences in the range of crops present (Table 5.4). In terms of the cereal species recorded, the predominance of (6-row) hulled barley and free-threshing wheats is clearly paralleled at other Islamic sites in the north-east, both in urban and rural areas. The evidence from La Mora Encantada provides an important record of both bread wheat and durum wheat, whilst at El Quemao durum wheat is also securely recorded. These are currently the first records of durum wheat in the Islamic period for the whole of Iberia, with only bread wheat recorded to date e.g. Calle Nuncio 13 in Madrid (Site 24: Ismodes Ezcurra et al. 2010). The absence, or near-absence of glume wheats at all the sites examined also reflects a wider pattern, and it is clear that emmer wheat and einkorn wheat were only cultivated on a small-scale in the Islamic period. It is also possible that glume wheats are contaminants of other crops (cf. Jones and Halstead 1995). Similarly, there is little to evidence at present to indicate that oats were an important crop in this period, although further archaeobotanical data would be required to confirm this.

However, one clear difference in the range of cereals recorded is the evidence for rye at all the sites examined for this PhD. At La Mora Encantada, rye is present in similar proportions to hulled barley and free-threshing wheats, whilst at El Quemao it is present in several samples. Interestingly, in the rural settlement of Las Sillas, rye was also recorded in comparatively large quantities relative to hulled barley and free-threshing wheat (Site 105: Ros et al. in press). In contrast, rye is entirely absent in the cities of Lleida, Balaguer and Tortosa (Sites 111, 133, 177: Alonso et al. 2014a). Further research is necessary to assess whether this reflects a genuine difference between rural and urban sites, or alternatively whether it reflects a geographical difference with rye more frequent in settlements away from the lowland areas of the Ebro Basin. In Madrid, a small number of archaeobotanical studies undertaken in urban contexts have also revealed a predominance of free-threshing wheat and hulled barley, with rare evidence for rye: Calle Nuncio 13 (Site 24: Ismodes Ezcurra et al. 2010), La Casa de San Isidro (Site 92: Serrano Herrero and Torra Pérez 2004), Plaza del Oriente (Site 139: Retuerce Velasco 2004). Frustratingly, none of these archaeobotanical studies undertaken in Madrid have been fully published. Further afield in the rural settlement Albalat, Extremadura, rye also forms an important component of the assemblages (Site 8: Ros et al. 2018, in press). The importance of rye in these rural sites may in part lie in its ability to produce higher yields on poorer soils than other cereals, and as a means of spreading risk by increasing crop diversity and exploiting wider ecological niches (Duby 1968:90; Halstead and Jones 1989). Similarly, rye has traditionally been highly valued for its straw for purposes such as thatching, weaving or tying together cereal sheaves (Hasltead 2014:78).

The crop isotope evidence from El Quemao and La Mora Ecantada are currently the first applications of this method on Islamic sites in Iberia. The evidence from El Quemao clearly points towards the rainfed cultivation of both free-threshing wheat and hulled barley (and probably also rye), with the possibility that these crops were cultivated together as a maslin. It has been widely highlighted that the unirrigated surrounding *alquerías* (hamlets/farmsteads) were used for cereal cultivation and this is reflected in the evidence from El Quemao (e.g. see Kirchner 2018:212-213 for mapped example in the Balearics). In comparison, at La Mora Encantada a different picture is provided by the crop isotope evidence, with hulled barley (and possibly rye) cultivated in rainfed areas, whilst free-threshing wheats, both bread wheat and durum wheat, were irrigated. Other researchers have drawn attention to the fact that irrigated areas were potentially used for the cultivation of cereals in al-Andalus, however, there is a lack of documentary evidence reflecting this (Jiménez Puertas 2007:16; Martín Civantos 2011: 406). Whilst large numbers of rural Islamic irrigation systems have been mapped and analysed, especially in the Balearics, direct archaeobotanical evidence for the crops cultivated in these irrigated areas is lacking (Kirchner 2011:62). Consequently, the crop isotope evidence examined here provides an important record of bread and durum wheat cultivation in these areas, probably in rotation with other crops such as flax, millets and potentially pulses further research is necessary to examine whether this pattern is replicated at other sites.

The large assemblages of broomcorn millet recovered from La Mora Encantada and El Quemao also provide an important record of millet cultivation in this period. Foxtail millet was only recorded in minor quantities at La Mora Encantada and Cabezo de la Cisterna, suggesting that its cultivation was undertaken on a smaller-scale, possibly as a contaminant of broomcorn millet crops. There is currently no evidence for broomcorn millet in the Islamic period at other sites in the north-east, whilst foxtail millet has only been recorded in trace quantities at Lleida (Site 111: Alonso 2005) and Tortosa (Site 177: Kirchner et al. 2014). The archaeobotanical evidence analysed for this PhD also indicates that sorghum is absent during this period in the sites/areas examined. Currently, the only archaeobotanical evidence for sorghum is at Benialí, Valencia, in the 14th-16th century (Site 16: Butzer et al. 1985b).

The first record of sorghum in documentary sources is in 11th century Islamic agronomic texts and it is thought to be a new 'Islamic' introduction. There are references to its cultivation in southern and eastern areas of Iberia, especially around Valencia, as well as in Mediterranean south-western France and northern Italy (Watson 1983:9-14; 1995:63; Hernández Bermejo and García Sánchez 1998; Guichard 2001; Glick 2004; Torró 2009; Saura Gargallo 2010). Watson (1983:9-14) also cites its cultivation in north-western Iberia, however, it may be confused with other millets considering the strong tradition of cultivation foxtail and broomcorn millet here (cf. Moreno-Larrazaba et al. 2015). There is some congruence between the documentary and archaeobotanical evidence for sorghum and it may genuinely be absent in the north-east during the Islamic period. However, its absence from El Quemao, which is near Valencia, is more surprising. Sorghum has been recovered from a few 11th-13th century sites in Mediterranean south-western France (Ruas et al. 2015; Pradat and Ruas 2017), whilst in northern Italy it has been recovered from the 5th/6th century onwards, though it appears to become more frequent in the c.9th-11th centuries (Castiglioni and Rottoli 2013; Rottoli 2014). Recently, the first archaeobotanical evidence for sorghum has been recovered in Morocco (Ruas et al. 2011). The absence of sorghum during the Islamic period in eastern areas is probably due to a lack of archaeobotanical research. Sorghum has similar cultivation and processing requirements to broomcorn and foxtail millet, enabling its potentially rapid adoption into pre-existing agricultural systems (Fuller and Stevens 2018).

Evidence for flax was also recorded at all the Islamic sites examined for this PhD, with a relatively large assemblage at La Mora Encantada. These are valuable records of flax cultivation given that the oil-rich seeds (which burn quickly) are likely to be significantly underrepresented in archaeobotanical assemblages (Märkle and Rösch 2008; Valamoti 2011). Gold-of-pleasure is also recorded at El Quemao, with mineralised seeds present, paralleling the evidence from the cities of Lleida, Balaguer and Tortosa (Sites 111, 133, 177: Alonso et al. 2014a). This adds further weight to the interpretation that gold-of-pleasure was consumed (cf. Butzer et al. 1985b). At Lleida, the geographer al-Himyari records flax as growing abundantly (Alonso et al. 2014a). Islamic agronomic texts widely refer to the cultivation of flax, often in association with hemp, for the production of fibre (García Sánchez 2001), although there is currently no evidence for hemp in the archaeobotanical record. At Lleida and Tortosa, mineralised flax seeds were recovered, potentially suggesting that they had been consumed (Sites 111, 177: Alonso et al. 2014a).

Pulses are generally poorly represented relative to cereals in the sites examined for this PhD, only being present in large quantities in one sample at El Quemao. This is typically thought to reflect a preservation bias, with pulses only occasionally becoming charred during parching/roasting or through the accidental/incidental charring of stray seeds (cf. Fuller and Harvey 2006). However, the same argument could also be extended to free-threshing cereals which are unlikely to come into contact with fire during processing; so the rarity of pulses probably does in part support the view that they were a less important component of diets than cereals. The pulses recorded include lentil, pea, grass pea, red pea, bitter vetch and pea. Considering the rarity of pulses, it is difficult to reliably infer which species were present and which were absent. No evidence for pulses has been recorded at Las Sillas (Site 105: Ros et al. in press), whilst only bitter vetch is recorded at Tossal de Solibernat (Site 180: Cubero 1990). In comparison, only lentil (including mineralised seeds) is recorded in minor quantities in the cities of Lleida and Balaguer (Sites 111, 133: Alonso et al. 2014a). It is interesting to note that the typical 'fodder' crops, red/grass pea and bitter vetch, are absent in these urban sites. No archaeobotanical evidence for either broad bean or chickpea has been identified; these are the only pulses recorded by the 12th century geographer al-Zuhri at Zaragoza (Ortega Ortega 2010:127). The absence of chickpea may reflect a preservation bias during charring (Jupe 2003 cited in Fuller and Harvey 2006:240).

At La Mora Encantada, a diverse range of fruit/nut species include sweet cherry, mulberry, blackberry, walnut, olive, fig and grape; these last two species are particularly abundant. In comparison, the sites examined at El Quemao and Cabezo de la Cisterna, produced a smaller less diverse assemblage of fruit/nut remains comprising mulberry, fig and grape. At El Quemao, hackberry is also represented. The less severe climate and evidence for irrigation at La Mora Encantada (and throughout the Huecha Valley) probably accounts for the greater diversity of fruit/nut species recorded. Most of these fruit/nut species have been previously recorded in the cities of Lleida, Balaguer and Tortosa, although a more diverse range of species are present there including plum, almond, peach, pomegranate, melon/cucumber, apple, apple/pear (Sites 111, 133, 177: Alonso et al. 2014a). The larger and more diverse range of fruits/nuts recorded at these sites probably reflects a preservation bias considering that many of the sampled features are cesspits/latrines with mineralised preservation. Despite this, in the sites examined for this PhD a surprisingly diverse range of fruits/nuts are recorded for a charred archaeobotanical assemblage. In particular, two species are recorded archaeobotanically for the first time: hackberry at El Quemao and mulberry at La Mora Encantada, El Quemao and Cabezo de la Cisterna.

Hackberry has previously not been recorded in Islamic sites in the north-east, however, it has been identified at other sites in al-Andalus and later medieval sites e.g. Castello de Silves (Site 46: Pais 1996), Besalú in Cataluña (Site Valenzuela et al. 2013), and Castillo de Turís in Valencia (Site 55: Carrión Marco and Pérez Jordà 2014). According to Islamic texts, hackberry was widely esteemed in al-Andalus, being cultivated in irrigated areas for the consumption of its fruit and for use of its wood (Carabaza Bravo 2004:83-86). The fruitstones of hackberry have a high probability of being recovered in archaeobotanical assemblages since they can preserve through biomineralisation. It is thus difficult to distinguish between a modern and an archaeological specimen, however, at El Quemao both biomineralised and charred fruitstones are present, supporting the interpretation that they are Islamic in date.

Similarly, mulberry is also recorded for the first time in the north east. In all cases, the fruitstones are preserved in charred form. In comparison, mineralised mulberry fruitstones have previously been identified in cesspits/latrines at Albalat in Extremadura (Site 8: Ros et al. 2018) and Rua dos Correiros[12] in Lisbon (Site 152: Bugalhâo and Queiroz 2005). Mulberry is also noted in a pit (cess pit/latrine?) at Plaza del Oriente, Madrid, however, no archaeobotanical report has been published for the site (Site 139: Retuerce Velasco 2004). Since all these finds are from

[12] The fruitstones are identified as black mulberry here, however, as noted above, the fruitstones of black and white mulberry cannot be reliably distinguished.

cesspits/latrines, it is likely that they reflect the consumption of the fruits. It is possible these finds reflect traded dried fruits.

In the sites examined for this PhD, it is unclear whether the white or black mulberry is recorded; the black mulberry is present in the Mediterranean from at least the Roman period (if not earlier), whilst the white mulberry is thought to be an 'Islamic' or medieval introduction linked to silk production (Carabaza Bravo 2004:98-101; Aubaile Sallenave 2012). Mulberry, probably black mulberry, has been recorded pre-Roman contexts in the Mediterranean, however, it is unclear how widely it was cultivated (van Zeist et al. 2001; Saboto et al. 2015). The leaves of the black mulberry can also be used for silk production, although a coarser, inferior silk is produced (Bergmann 1940). Evidence for silk production is recorded in a *fatwa* (legal document) in 1084 in Zaragoza, where reference is provided to the illegal sales of mulberry leaves (Lagardère 1995:no.209). The 10th-11th century geographer al-Zuhri noted that Zaragoza was famous for its textiles (Constable 1996:176). In the south of al-Andalus, an extensive study of documentary sources highlights the widespread cultivation of mulberry trees for silk production, where it was an important cash-crop for several centuries (Lagardère 1990; 1993:391-412). The Geniza documents from Cairo record that silk was an export from al-Andalus to other Mediterranean areas (Goitein 1961; Constable 1996:173-181).

It is likely that some of the fruit/nut species and pulses referred to above were cultivated in irrigated areas, either in the larger *huerta* or, more likely, in a more intensively managed *huerto* (market-garden) (cf. García Sánchez 1995; Lagardère 1993:64-86). For instance, the crop isotope evidence from El Quemao points towards the cultivation of lentils in irrigated areas, and this is possibly also reflected in the weed assemblage. At La Mora Encantada, it is unclear whether the lentils were intensively irrigated. Clear evidence for other 'garden' crops is slight, however, relative to their small size, the more intensively managed and irrigated *huertos* potentially contributed disproportionately to diets (cf. Grigg 1974:125-128; Halstead 1987:75). Recently, Peña-Chocarro and Pérez Jordà (2019) have reviewed the archaeobotanical evidence for 'garden' crops in al-Andalus, highlighting a wide range of fruits/nuts and pulses which were cultivated, with less clear evidence for vegetables, herbs and spices. A research problem from an archaeobotanical perspective is the difficulty of identifying many of these other 'garden' crops (Greig 1996). Similarly, where potential garden crops are recorded in the archaeobotanical record it can be difficult to establish whether they were consumed, or whether they are a wild/weed taxa (e.g. mints, rosemary, common purslane, common vervain) introduced through other taphonomic processes.

As noted above, previous archaeobotanical research has identified spices/condiments at Lleida and Tortosa, including celery, nigella and fennel in cesspits/latrines, probably reflecting their consumption (Sites 111, 177: Alonso et al. 2014a). Evidence for fennel has also been identified at other Islamic sites e.g. Castelo de Mértola and Castelo de Silves in the south of Portugal (Sites 45, 46: Pais 1996; Mateus and Queiroz 2006). Similarly, celery has been recorded in a waterlogged/mineralised latrine deposit at Rua dos Correiros, Lisbon (Site 152: Bugalhâo and Queiroz 2005). Fenugreek is recorded at Las Sillas which is currently a unique record in al-Andalus (Site 105: Ros et al. in press). In other areas of al-Andalus, coriander is recorded at Albalat in Extremadura (Site 8: Ros et al. 2018) and at Casa dos Bicos (Site 40: Queiroz and Mateus 2011) and Santarém in the south of Portugal (Site 65: Queiroz 2001). At Yakka, Murcia, bottle-gourd has been identified for the first time, although little information is given on the identification of this species (Site 189: Ruiz Molina 2000). Watermelon has been also been identified for the first time in a cesspit/latrine at Sa Capelleta, Ibiza (Site 154: López and Marlasca 2009); a potentially 'new' Islamic introduction (Watson 1983:58-61; see however, Paris 2015 for its earlier origin). The archaeobotanical evidence analysed for this PhD at El Quemao adds garlic to this list of garden crops. There are few archaeobotanical finds of garlic cloves in Europe, probably because the cloves are unlikely to become charred and preserve (Bakels and Jacomet 2003; Badura et al. 2013).

A wider diversity of vegetables and other garden crops are unsurprisingly recorded in Islamic agronomic texts than the archaeobotanical recorded, including several species which are either thought to be new introductions, or at least became more widely cultivated in this period (Lagardère 1993:64-86; Trillo San José 2004:47-50; Albertini 2013:144-145). For example, two of these 'new' introductions are aubergine and spinach, both of which could have been easily and quickly incorporated into the existing spectrum of garden crops, whilst new fruit tree species (e.g. citrus fruits) and other crops (e.g. sugarcane) required more specialised cultivation and took longer to establish (cf. Halstead 2014:286). No documentary references have been identified to either spinach or aubergine in north-east Iberia, nor are they recorded in archaeobotanical assemblages. However, their absence may reflect a preservation bias and at present it is unclear how widely some of these 'new' crops were diffused across al-Andalus. For example, citrus fruit seeds and apricot (both new introductions) have at present only been recorded in the south of al-Andalus (van Leeuwaarden and Querioz 2003; Morales et al. 2019).

Similarly lacking for this period is clear archaeobotanical evidence for imported crops and condiments/spices, including exotic or luxury species. On the basis on archaeobotanical research undertaken in central and northern Europe, it would be expected that imports would be more common in urban centres, ports and high status sites (cf. Livarda and van der Veen 2008; Livarda 2011). In fact, the widespread trade of exotic crops is a feature of the medieval period across Europe. Dried or preserved fruits such as olives, figs and raisins were widely traded along the Mediterranean coast and it is possible that they are represented in archaeobotanical assemblages in the north-east (Constable 1996:161-164, 181-185; Puig 2005; Ruas et al. 2005b). However, distinguishing between a locally cultivated and a traded olive, fig or raisin is problematic from an archaeobotanical perspective since these crops were also widely cultivated. In other cases, 'novel' or 'exotic' crops such as cotton, rice, dates and sugar are recorded in documentary sources as traded commodities along the Mediterranean coast (Constable 1996; Puig 2005; Ouerfelli 2008; Kirchner 2018:208). There is currently little to no documentary or archaeological evidence which indicates that rice, cotton, dates or sugarcane were widely cultivated (if at all) in many areas of the north-east.

To summarise the key findings of archaeobotanical research undertaken on Islamic sites:

- Free-threshing wheats and (6-row) hulled barley are the dominant cereals. Glume wheats are either absent or present in trace quantities. There is no clear evidence for the cultivation of oat. Rye is (largely) absent in urban sites, whilst there are indications that it was a more important crop in rural areas. The archaeobotanical evidence from La Mora Encantada and El Quemao provides the first diagnostic evidence for the cultivation of durum wheat. Bread wheat is also recorded at La Mora Encantada.

- Millets are very rare or absent in previously analysed archaeobotanical assemblages, whereas broomcorn millet is abundant at La Mora Encantada and El Quemao. There is only slight evidence for foxtail millet. Sorghum, a new 'Islamic' introduction, is absent in the archaeobotanical record.

- Flax is typically recorded in low numbers, although a very large assemblage has been recovered from Melque (Site 118: Arnanz et al. 1999) highlighting the importance of its cultivation. At all the sites examined for this PhD, flax was recovered. There is no evidence for other fibre crops (e.g. hemp, cotton).

- As in the preceding period, pulses are generally poorly presented and the species recorded include pea, lentil, grass pea, red pea and bitter vetch. A large number of pulse seeds were recovered from El Quemao, providing a valuable record of their cultivation. Broad bean is absent on the basis of the current evidence.

- A diverse range of fruit/nut species are recorded for this period, especially in urban sites with cesspits/latrines providing excellent preservation. The species recorded include cucumber/melon, walnut, apple, olive, pine nut, almond, plum, sweet/sour cherry, peach, pomegranate, grape and fig. Evidence for carob is recorded in charcoal assemblages in Valenica, hinting at the exploitation of the carob pods and seeds. Other 'garden' species recorded include celery, fennel, nigella and fenugreek. The archaeobotanical evidence analysed for this PhD adds mulberry, hackberry and garlic to this list of crops. There is currently no archaeobotanical evidence for 'new' crops such as spinach, aubergine or citrus fruits in the north-east.

5.5 Later medieval period

Figure 5.4 shows the location of previous archaeobotanical studies undertaken on later medieval period sites in the north-east.

Very little archaeobotanical research has been undertaken on later medieval sites in the north-east to provide a comparison with the evidence analysed in the Huecha Valley for this PhD. At present, the best comparison is with l'Esquerda in the north of Cataluña (Site 107: Cubero et al. 2008). The assemblage from l'Esquerda, dating between the 11th-13th centuries, is currently the largest (n=1038 charred remains) published for the later medieval period in the north-east. Of particular note is an assemblage recovered from a granary destroyed by fire in the 13th century, from which the majority of the charred plant remains were recovered. A diverse range of cereals are recorded here including hulled barley, oat, emmer wheat, free-threshing wheat, einkorn and rye in order of abundance. The assemblage is, however, dominated by pulses, with bitter vetch the most common species, forming 35% of the total number of remains and the authors suggest a fodder crop origin for the assemblage (Cubero et al. 2008) Other pulses recorded include lentil, vetches and, unusually, chickpea, which is recorded for first time in a medieval deposit in Iberia. The rarity of chickpea may, however, reflect a preservation bias and charring experiments have indicated that it is less likely to preserve than either lentils or peas (Jupe 2003 cited in Fuller and Harvey 2006:240). Low numbers of millet grains are present, with broomcorn millet the only securely identified species. There is slight evidence for fruit/nut remains, comprising grape and almond.

Also in Cataluña, small archaeobotanical assemblages have been recovered from 10th-12th century Ca l'Estrada (Site 21: Fortó García et al. 2009) and 10th-13th century Besalú (Sites 17-18: Valenzuela et al. 2013). At Ca l'Estrada, the assemblage is comparable to l'Esquerda, with free-threshing wheat, hulled barley, millets and pulses (lentil, pea) recorded, although oat and glume wheats are absent (Site 21: Fortó García et al. 2009). Similarly, at Besalú, the assemblage includes free-threshing wheat, hulled barley, oat, broomcorn millet, lentil, fig, grape and hackberry (Sites 17-18: Valenzuela et al. 2013). In Andorra, at Camp Vermell, a small assemblage dating broadly to the 8th-12th centuries, primarily includes free-threshing wheat and hulled barley, with slight evidence for naked barley, rye, emmer wheat, broomcorn millet, pulses (red/grass pea, broad bean) and fruits/nuts (grape, peach) (Site 32: Alonso et al. 2010). There is currently no archaeobotanical data from later medieval urban sites in the north-east.

In contrast to the dearth of documentary evidence for the preceding Islamic period, the Christian conquests in the 11th-12th centuries generated a large body of documentary evidence, particularly the *repartimientos* (land registers) (Glick 2005:100-104). The *repartimientos* provide valuable information on the reorganisation of agricultural spaces, especially irrigated areas, although specific information concerning the crops cultivated is often sparse (Kirchner 2019). It has been widely highlighted that a corollary of the Christian conquests and the shift to a feudal regime was the expansion and modification of irrigation systems together with an increase in olive groves, viticulture and, above all, cereal cultivation (e.g. Corral Lafuente 1983; Bolòs 1993, 2001; Barceló 1989, 1995; Stalls 1995:216-220; Laliena Corbera 1986, 1989, 1998, 2007; Laliena Corbera and Ortega Ortega 2011, 2012; Ortega Ortega 2010; Pico Torné 2015; Torró 2019; Rodrigo Estevan 2007; García-Contreras Ruiz 2018; Kirchner 2012, 2018, 2019; Kirchner et al. 2014; Virgili 2010, 2018; Kirchner and Virgili 2019). This 'cerealisation' reflects a widespread phenomenon across Europe (cf. Comet 2004). However, as Butzer et al. (1985a) have highlighted in the case of Valencia, the Christian conquests did not lead to the abandonment of the new 'Islamic' introductions such as sugar and rice; instead there is documentary evidence for the increasing commercialisation of these crops, especially sugar until the 15th century (*contra* Watson 1983; cf. Vidal 1973; Constable 1996:233; Coulon 2001; Glick 2005:223; Ouerfelli 2008).

Where specific information on the cereals cultivated is provided in documentary sources, wheat appears to hold the greatest importance, although it is unclear which species is being referred to. This is then followed by barley, and to a lesser extent by rye and oat. There is some evidence to suggest that cereals were cultivated in both irrigated areas, with more stable and higher yields achieved under irrigation, enabling higher rents to be extracted (e.g. Laliena Corbera 1989; Bolòs

1993, 2001; Kirchner 2012:34; Torró 2019). A shift in the use of irrigated areas for cereal cultivation has also been documented elsewhere e.g. Valencia (Torró 2009; Guinot Rodríguez 2019). At the same time, an expansion in rainfed cereal cultivation has been identified. Olive groves may also have expanded in this period, although given that olive trees take a long time to establish it is difficult to ascertain the full extent of their cultivation before the Christian conquests (e.g. Tortosa: Kirchner et al. 2014). Flax and hemp are widely recorded from the 12th-13th century onwards in documentary sources and by the 14th century they are important cash-crops across the north-east (Navarro Espinach 2003b). Crops not directly linked to, or less frequently received in rent are given less attention and there are only sporadic references to other crops such as millets, fruits/nuts (excluding grape and olive), pulses and vegetables in earlier periods (e.g. Laliena Corbera 1989).

Placing the archaeobotanical evidence for the north-east into a wider context, it is evident that a similar range of crops are recorded in later medieval deposits in the north of the Iberian Peninsula in País Vasco at Catedral Vitoria (Sites 60-62: Pérez-Díaz et al. 2015), Zaballa (Sites 192-193: Sopelana 2012) and Zornoztegi (Site 198: Sopelana and Zapata Peña 2009). At these sites, archaeobotanical assemblages are also dominated by free-threshing wheats and hulled barley, with evidence for oat, millets (both broomcorn and foxtail millet), flax, and fruits/nuts also recovered. At Catedral Vitoria in particular, rye forms an important component of the assemblages (Sites 60-62: Pérez-Díaz et al. 2015). In Mediterranean south-western France, documentary and archaeobotanical evidence show clear similarities in the range of crops present (Puig 2005; Ruas 2005; Ruas et al. 2005a, b; Ros et al. 2014a, 2019; Ruas et al. 2015). The dominant cereals are hulled barley and free-threshing wheat, with diagnostic bread wheat rachises identified at some sites. Common oat and rye are also recorded at several sites, whilst glume wheats occur frequently although are present in low proportions in relation to other cereals the (Ruas 2007). An archaeobotanical assemblage from La Gravette, an 11th century granary associated with a seigneurial household, was dominated by free-threshing wheat, with other cereals of secondary importance including hulled barley, rye, common oat and einkorn wheat (Ruas et al. 2005a). Other crops recorded include both flax and hemp, pulses (broad bean, grass/red pea, lentil, pea, vetch) and fruits/nuts (grape, olive, hazel nut, walnut, sweet/sour cherry, plum, fig and mulberry).

Two new crops are also recorded for this period, spinach and sorghum. At Montaillou in the French Pyrenees, charred remains of spinach (achenes, seeds) were recovered from 12th-13th century contexts in a castle; these are amongst the only finds in the Mediterranean (Hallavant and Ruas 2014). The only other archaeobotanical record of spinach is in 13th century Sicily at Mazara del Vallo (Carver et al. 2019). It is suggested that spinach was introduced via al-Andalus, where it is recorded in documentary sources from the 11th century (Hallavant and Ruas 2014; cf. Hernández Bermejo and García Sánchez 1998). A further new crop is sorghum, which occurs in small quantities in multiple sites dating between the 11th-13th centuries across Mediterranean south-western France (Ruas et al. 2015).

Analysis of documentary sources for the later medieval period in Mediterranean south-western France adds further information on the range of crops cultivated and imported (Puig 2005; Ros et al. 2014a). The sources provide references to staple crops such as *forment/frumentus,* probably bread wheat, alongside barley, oat and rye from the 12th-13th centuries onwards. There is some evidence for the cultivation of maslins, either comprising mixes of wheat/barley or wheat/rye (cf. Comet 1992:249). Pulses are also recorded, the most important of which is broad bean, with other species including pea, grass/red pea, lentil, vetch and chickpea; of these species, only chickpea is absent in the archaeobotanical record. The documentary sources also provide evidence for a range of cultivated and wild fruits, including imported exotic species to al-Andalus: melon, cucumber, peach, apple, pear, fig (imported) citrus fruits (imported?) and date (imported) (cf. Constable 1996:220-221). There is also evidence for rice in the documentary sources and it is probably an import since there is little evidence to suggest it was cultivated until the c.15th century. Finally, a diverse range of fruits/vegetables are recorded (predominately in later periods), including leek, cabbage, carrot, onion, shallot, garlic, turnip, gourd, cucumber, spinach, chard and aubergine. Whilst some of these species have also been verified in archaeobotanical deposits, aubergine (first recorded in the 13th century) is currently absent in the archaeobotanical record (Ruas et al. 2015). Evidence for spinach and aubergine also recorded in 14th-15th documentary sources, including cookbooks, in north-east Iberia; the most common vegetables being cabbages, leeks, onions and garlic (Sarasa Sánchez 2013; Bertrán Roigé 2013; Vogelzang 2008; Constable 2018:130). Another important crop recorded is saffron, yet there is no archaeobotanical evidence for this.

How does this evidence compare with the archaeobotanical assemblages analysed for this PhD at Palacio de Bulbuente, Castillo de Grisel and the Casa Conventual de Ambel in the Huecha Valley (Table 5.4)? The three dominant cereals in the sites analysed are hulled barley, free-threshing wheat and rye, with oat and glume wheats (emmer wheat and probably einkorn) of secondary importance. At Palacio de Bulbuente, diagnostic free-threshing wheat rachises confirm the presence of both bread wheat and durum wheat for the first time in the later medieval period.

The low proportions of glume wheats parallel the evidence from other sites in the north-east and Mediterranean south-western France, probably reflecting their widespread, though small-scale cultivation. As outlined previously, the cultivation of emmer wheat and einkorn may be related to their use to prepare specific foodstuffs, or for the use of their straw (Hillman 1984b; Halstead 2014:284; Peña-Chocarro et al. 2015). The high proportion of rye, and to a lesser extent, oat at Palacio de Bulbuente reflects wider shift in the archaeobotanical record across Europe (Behre 1992; Comet 1992, 2004; Bouchette et al. 2011; Squatriti 2016).

The crop isotope evidence from Palacio de Bulbuente points towards the cultivation of hulled barley and free-threshing wheat in both rainfed and irrigated areas. As in the Huecha Valley, several studies across the north-east have documented the reorganisation and modification of 'Islamic' irrigated areas following the Christian conquests. In some cases, these irrigated areas were increasingly used for the cultivation of cereals, and this is reflected in the evidence from Bulbuente. Concurrently, there is also evidence for a shift towards more extensive forms of cereal cultivation in rainfed areas, entailing less-labour inputs per area of land. Oat and rye are well-adapted to cultivation in these low-intensity regimes, being well-adapted to marginal and dry soils. The crop isotope evidence suggests that rye was cultivated in rainfed areas, although a larger modern reference dataset is required to support this. This extensificiation was probably accompanied by an expansion in the use of draught animals, and consequently requirements for fodder and pasture would have increased (Halstead 1995). This is likely to be an important factor in explaining the increase in oats, together other fodder crops such as *alcaceres* (green barley), and potentially also millets and pulses, especially bitter vetch (cf. Halstead 2014:52). Overall, it is suggested here that the evidence from Palacio de Bulbuente reflects the local reverberations of this expansion in cereal cultivation which accompanied the Christian conquests. This was characterised by an increase in crop diversity and an increase in yields/surplus through cultivation in irrigated areas and through extensification.

Millets are recorded at all the sites, with broomcorn millet the dominant species, paralleling the evidence from other sites in north-east Iberia and Mediterranean south-western France. Foxtail millet is only present in minor quantities in the sites analysed, however, this crop is abundant in the north of the Iberian Peninsula in País Vasco. Similarly, in the north-west, foxtail millet is also abundant. It is difficult to directly identify when millet cultivation increased, however, it is evident that by the later medieval period (c.12th century onwards) broomcorn millet was widely cultivated in the north-east, whereas foxtail millet is rare.

Evidence for other crops is relatively slight. Pulses form a minor component of the assemblages analysed, with lentil, pea, bitter vetch and broad bean recorded, which is the most abundant species. Similarly, broad bean appears to have been the most important pulse species in other areas. Two crops not recorded in the assemblages are grass/red pea and chickpea; this may simply reflect a lack of evidence recovered for these crops, as opposed to their genuine absence in the archaeobotanical record and, in the case of chickpea this is likely to reflect a preservation bias (cf. Jupe 2003 cited in Fuller and Harvey 2006:240).

Flax is recorded at all the later medieval sites examined for this PhD, highlighting its widespread cultivation. This valued crop has previously not been recorded for later medieval assemblages in the north-east, however, it is present in the north of the Iberian Peninsula and in Mediterranean south-western France. On the basis of the archaeobotanical evidence, little can be said concerning the scale of flax cultivation. Instead, it is necessary to rely on the documentary sources which point towards the increasing commercialisation of flax cultivation, together with hemp, especially from the 14th century onwards. It is anticipated that as further archaeobotanical research is undertaken, evidence for flax will increase, and hemp is likely to be recovered.

The evidence for fruit/nut remains is comparatively slight in terms of their frequency. Despite this, a diverse range of crops are recorded including peach, almond, plum(?), hazel nut, mulberry, walnut, olive, fig and grape. All these species are recorded in documentary sources between the 12th-14th centuries, with mulberry added a century later. There is no archaeobotanical evidence for mulberry in the later medieval period in the north-east, however, it is recorded in Mediterranean south-western France. Archaeobotanical evidence for mulberry is currently very rare in the Iberian Peninsula for the later medieval period, only being recorded in Portugal in a Medieval Islamic/Christian deposit in Casa dos Bicos (Site 40: Queiroz and Mateus 2011) and in a post-medieval deposit at Santa Clara a Velha (Site 156: Queiroz et al. 2006). The evidence for mulberry at Palacio de Bulbuente is therefore an important record of this crop in the later medieval period. As outlined above in reference to the Islamic period, there is currently no clear archaeobotanical evidence for imported fruit/nut species or spices in this period (cf. Bouby 2005; Puig 2005; Ruas et al. 2005b).

Grape pips/seeds are ubiquitous in the sites examined for this PhD, with some evidence also for fruit/berry fragments and a potential 'pressed skin'; it is possible that these remains are all linked to wine production. It is difficult to explain why grape seeds/pips so frequently become charred given that fruit/nut species are typically thought to be underrepresented in charred assemblages (cf. van der Veen 2007). From an archaeobotanical perspective it is difficult gauge any change in the importance of viticulture, although theoretically it would be expected that grape seeds/pips would occur in higher densities in later medieval deposits compared to earlier periods. With further research, it may be possible to identify this.

To summarise the key finding of archaeobotanical research undertaken on later medieval sites:

- Free-threshing wheats and (6-row) hulled barley are the dominant cereals. Glume wheats are present in low numbers in several sites highlighting the widespread, small-scale cultivation of these crops. Both oat and rye are major crops in this period. The archaeobotanical evidence from Palacio de Bulbuente provides the first diagnostic records of both bread wheat and durum wheat for the later medieval period.

- Broomcorn millet is the most widely cultivated millet species in the north-east, and although foxtail millet is widely recorded it only occurs in low numbers. An exception to this pattern are sites in the north in País Vasco where both broomcorn and foxtail millet are cultivated in similar proportions. Evidence for broomcorn millet was recorded at all the later medieval sites analysed for the PhD.

- Flax and hemp are widely recorded in documentary sources for this period. However, archaeobotanical evidence for flax is typically slight, whereas hemp is currently absent from the archaeobotanical record in the north-east of the Iberian Peninsula. Hemp has only been recorded in one assemblage in Mediterranean south-western France.

- Pulses are present in low numbers at most sites, including pea, lentil, grass pea, red pea, bitter vetch and broad bean. Chickpea is also recorded in an archaeobotanical assemblage in this period for the first time, however, its absence at other sites may reflect a preservation bias.

- The range of fruit/nut species and vegetables present shows continuity with the preceding Islamic period and no new species are identified. This includes species including cucumber/melon, hazel nut, walnut, apple, olive, almond, plum, sweet/sour cherry, peach, carob, mulberry, carob, fig and grape. The documentary sources for this period point towards an expansion in viticulture.

5.6 Discussion: regional and pan-regional perspectives

The overall pattern that emerges from the evidence is one of broad continuity in the crop spectrum. There are only minor adjustments in the range of crops of cultivated, although a general trend towards increasing crop diversity can be detected through time. In comparison, there appear to have been more significant changes in the nature of farming practices (e.g. irrigation) and in the organisation and management of agriculture (e.g. modes of production); the manifestation of these changes in the archaeobotanical record are only faintly discernible at present. The Islamic conquests did not lead to a clear and definable break in the 'traditional' rhythms of Mediterranean agriculture, but rather a series of more incremental and gradual changes which can be traced between the end of the Roman period through to the later medieval period. Despite this, there were undoubtedly some innovations in agriculture after the Islamic conquests. The most important of these was a change in farming practices with an expansion in irrigation, alongside the diffusion of new cultivars and crops. A pressing question is how widely these new 'innovations' were adopted. From the evaluation of the evidence outlined above, some key points can be drawn out and it is possible to revisit some of the questions and themes outlined at the beginning of this thesis:

Firstly, there is continuity in the cultivation of the two main cereals – hulled barley and free-threshing wheats from the Roman to later medieval period. In most cases, it is apparent that the 6-row form of hulled barley was the most widely cultivated type, whilst evidence for the 2-row form is currently slight. In terms of the free-threshing wheat species cultivated, the relative importance of bread wheat and durum wheat cannot yet be resolved due to a paucity of diagnostic evidence. At present, durum wheat has only been securely recorded in the Islamic period. Further archaeobotanical research is necessary to examine whether the Islamic conquests led to the re-introduction, or at least expansion in the cultivation of durum wheat. Modern crop DNA evidence perhaps hint at the spread of different durum wheat landraces (Moragues et al. 2007; Oliveira et al. 2012) It is conceivably that an expansion in the cultivation of free-threshing wheats occurred in tandem with the growth of urban centres throughout the Islamic and later medieval period, however, the is insufficient data to support this argument. Certainly, in the later medieval period documentary sources indicate that 'wheat' had become a commercial crop, although earlier evidence for this is difficult to find.

Secondly, a broad pattern of increasing crop diversity can be identified, with an expansion in the cultivation of oat, rye and millets (especially broomcorn millet). Whilst these crops were already known by the Roman period, an expansion in their cultivation can be broadly dated to the late

Roman to early medieval period. By the Islamic and later medieval period, these crops appear to have been widely cultivated, although comparative data from later medieval urban sites is currently absent. This increase in oat and rye cultivation reflects wider patterns in medieval archaeobotanical record across Europe, whilst millet cultivation also appears to have increased in more southerly areas. The expansion in the cultivation of these crops may in part lie in their ability to fill specific niches within agricultural systems. Both rye and oat are tolerant of poor growing conditions, coping with either higher altitudes, low fertility or limited water availability. Similarly, millets are tolerant of poor soils and due to their short, summer growing cycle they could act as a catch-crop. Millets could potentially have been planted during fallow periods, intensifying land-use in the summer period (Halstead 2014:21). These crops could have served as animal fodder, or as food and their use in bread is well documented (e.g. Rubio 2002). A corollary of this increase in crop diversity may have been an expansion in extensive forms of cultivation, entailing fewer labour inputs per area of land, yet higher provisions of fodder for draught animals. There is circumstantial evidence for the increasing 'cerealisation' of the economy of the following the Christian conquests, broadly reflecting the shift to a feudal regime with a 'land-based' or 'rent-based' system in which seigneurial lords extract revenues though agriculture (cf. Glick 2005; Wickham 1984, 2005:58).

It has been suggested that greater emphasis was placed on polyculture during the Islamic period, with irrigated arboriculture, viticulture and vegetables being of particular significance (though with cereals still forming the mainstay of diets) (e.g. Barceló 1985; Watson 1983; Glick 2005). In comparison, by the later medieval period there is evidence, primarily from documentary sources, to suggest that greater emphasis was placed on the cultivation of a less varied 'monoculture' of cereals, albeit with arboriculture, viticulture and vegetables still forming an important component of farming practices (Kirchner 2018). Seigneurial lords sought to extract greater revenues by promoting the more widespread cultivation of cereals, and importantly they also maintained monopolies on flour mills (Glick 2006).

Thirdly, a diverse range of fruit/nut species (and possibly vegetables), both wild and cultivated, are recorded in the Roman period, highlighting the early development of arboriculture and viticulture (which has prehistoric antecedents cf. Alonso and Bouby 2017; Pérez Jordà et al. 2017). The species recorded include hazel nut, fig, olive, stone pine, apple/pear, sweet cherry, plum, almond, blackthorn/sloe, peach, pomegranate, acorn, melon, blackberry, walnut and grape. In the early medieval period, mulberry is added to list of species, although this crop may have been present in earlier periods. Despite this, mulberry appears to become more widely diffused and cultivated during the Islamic period. In other cases, it is currently not possible to discern any clear shifts in the archaeobotanical record in the presence/absence of fruit/nut species, or their relative importance to one another. The few documentary sources for the Islamic period allude to the abundance of fruits grown in the north-east, and the development of irrigated arboriculture is viewed as a defining feature of the Islamic period. To some extent this is reflected in the archaeobotanical record in urban areas, which highlights the diverse range of species consumed. For the later medieval period the picture is less clear due to the paucity of archaeobotanical evidence, however, one change recorded in documentary sources is an expansion in viticulture following the Christian conquests.

Fourthly, the cultivation of flax is recorded from at least the early medieval period, and archaeobotanical finds of flax are widespread in the Islamic period. It is likely that flax was primarily cultivated for its fibre, possibly in association with hemp although there is currently no archaeobotanical evidence for this latter crop. By the later medieval period, documentary sources indicate that both flax and hemp were important commercial crops, although the commercialisation of these crops probably has earlier antecedents in crops in the Islamic period.

Fifthly, the development and expansion of irrigated farming is often viewed as a defining feature of the Islamic period in both urban and rural settings. At present, few irrigation systems have been subject to detailed research using evidence from archaeological research and documentary sources in the north-east. A note of caution is needed in assessing the nature and scale of irrigation during the Islamic period due to a lack of dating evidence. Current understanding is based overwhelmingly on later medieval archaeological and documentary evidence which is projected retrospectively into the Islamic period. Similarly, we do not a have clear picture of irrigation systems pre-dating the Islamic conquests. Despite the centrality of irrigation to discussions of the Islamic and later medieval period, most knowledge of the crops cultivated in these areas is based on anecdotal evidence. Archaeobotanical research has contributed little to this important topic, and this PhD highlights that significant potential lies in the use of crop isotope evidence to infer the use of rainfed and irrigated areas for the cultivation of cereals and pulses.

Finally, there is currently no clear evidence for the introduction of new crops or for exotic imports in the archaeobotanical record. Does this reflect their genuine absence or a preservation bias? Whilst some new crops and imports are likely to have been rare, or primarily restricted to urban centres, ports and high status sites, a preservation bias is an important factor in explaining their absence. New crops and imports are only likely to be recovered in exceptional circumstances in charred assemblages, and instead they are more likely to be preserved in specific burial environments such as cesspits/latrines or in waterlogged deposits. This is particularly the case where the seeds of fruits or vegetables have a high probability of being consumed such as in citrus fruits or aubergines. At present, sites with waterlogged preservation are exceptionally rare, with none yet identified in the north-east, and only a handful urban sites with cesspits/latrines have been investigated for the Islamic period. In comparison, no (published) urban sites have been examined in the later medieval period. In other cases, the absence of crops such as rice or sorghum probably reflects the case that very limited archaeobotanical research has been undertaken in areas where these crops are thought to have been grown (e.g. the Valencia region).

As is outlined below in more detail, there is growing evidence for diffusion of new crops across the Mediterranean with a broadly Islamic/medieval timescale. It is hypothesised that as further research is undertaken, evidence for new crops and exotic imports will increase, especially in urban centres. In particular, with the growth of urban centres during the Islamic period, it might be expected that agriculture became increasingly commercialised with a concomitant expansion in cash-crops and the cultivation of novel, 'new' species as luxuries (Watson 1995:67; Horden and Purcell 2000:259-260; Martínez Enamorado 2003:114-118; Boivin et al. 2012, 2014; Molinari 2015; Amichay et al. 2019). In comparison, rural areas are likely to have been more conservative in the adoption of new crops, cultivars and farming techniques, although there was likely some space for experimentation, potentially on a small-scale in gardens by peasant communities (Johnson 1972; Netting 1993). Migration is often linked to the movement of crops, and this may have been an important factor (in this case Arabs and Berbers, section 1.4.3) in explaining some of the changes in cropping patterns and the use of irrigated areas (cf. Grew 1999:3). This is, however, a contentious issue, with some researchers increasingly questioning the relationship between agriculture and the migration of Arabs and Berbers (e.g. Manzano Moreno 2018). At present, it is difficult to evaluate in detail the wider impact of the Islamic conquests on agriculture until further archaeobotanical research is undertaken in other areas. Nevertheless, the results presented here add nuance to our understanding of this period, providing valuable insights into rural economies and a longer-term perspective on agriculture.

6 Conclusions

This final chapter summarises some of the wider implications of the evidence presented in chapters 3, 4 and 5. It briefly re-examines the context of this research, focusing on the idea of an Islamic agricultural revolution across a wider area and recent contributions of archaeobotanical research to this topic. The chapter concludes with a reflection on the research themes of this PhD and avenues for future research.

The impact of the Islamic conquests on agriculture is one of *the* big research questions in the history of the Mediterranean and beyond. In particular, Watson's (1974, 1981, 1983) grand narrative of a sweeping agricultural transformation in the first centuries of the early Islamic world has been highly influential, remaining an enduring concept. Sherratt (2004:28) stressed that "this was the most important movement of crops before the Columbian exchange" and others have drawn comparisons between the spread of Islam and crop globalisation (Squatriti 2014b; Boivin et al. 2014; Boivin 2017; van der Veen and Morales 2017).

Nonetheless, it is a concept which has also been widely challenged and critiqued (e.g. Aubaile Sallenave 1984; Johns 1984; Brett 1985; Butzer et al. 1985a; Butzer 1994; Horden and Purcell 2000:258-263; Reihl and Nesbitt 2003; Decker 2009, 2011). For example, some have considered the model overly simplistic, whilst others have questioned how widely new innovations were adopted. However, one of the main critiques levied against the 'Watson thesis' concerns the proposed timing of these agricultural innovations – are they Islamic in date or do some of the innovations have earlier antecedents? It is now widely acknowledged that some elements considered to be 'Islamic' innovations such as summer cropping or new methods of irrigation were already present in areas of the Mediterranean and Middle East before the Islamic conquests (e.g. Aubaile Sallenave 1984; Butzer et al. 1985; Malouta and Wilson 2012). This can also be extended to the list of supposedly 'new' crops, with a considerable body of research highlighting their pre-Islamic diffusion in some cases (e.g. Rowley-Conwy 1989; Pelling 2008; Decker 2009). In particular, one of the most prominent critiques is by Decker (2009), who focuses on the examples of durum wheat, cotton, rice and artichoke, noting that there is good evidence for these crops before the Islamic period. It is often overlooked that Watson (1983) did actually note that some of the new crops and techniques of irrigation were already present in earlier periods (e.g. sorghum), yet they were not widely diffused; however, many would now suggest that greater emphasis needed to be placed on the longer-term, pre-Islamic perspective.

This last point raises a question concerning the mechanisms of diffusion. In particular, it has been widely highlighted that the diffusion processes of agricultural technologies and crops are often complex and protracted, potentially involving numerous (re-)introductions of a crop or technology prior to its more widespread uptake (van der Veen 2010; Boivin et al. 2012, 2014; Ruas et al. 2015). Similarly, the use and significance of a crop can vary significantly between different periods. Walshaw (2010) provides the example of rice in east Africa; there was a long delay of centuries between its initial, small-scale cultivation and its far more widespread uptake with the 'Islamisation' of the area. Similarly, cotton in the Middle East provides another example; archaeobotanical evidence confirms the pre-Islamic cultivation of cotton, yet it is not until after the Islamic conquests that we see a widespread intensification of its cultivation (Bulliet 2009; Bouchard et al. 2011; Brite and Marston 2013). Consequently, it is more significant to identify the cumulative impact of various agricultural innovations (van der Veen 2010; cf. Rowley-Conwy 1989). The question then shifts from identifying the first introduction of a new crop or irrigation technology, to assessing the degree of continuity versus change in agriculture. Do we see a clear and definable break in agriculture after the Islamic conquests, or instead a picture of longer-term continuity?

Though most researchers now acknowledge that issues remain with the 'Watson thesis', the idea that the early Islamic world provided a medium for the diffusion of crops and farming practices, notably irrigation, has remained highly influential and it continues to stimulate research and debate (Squatriti 2014a). When originally conceived the 'Watson thesis' was almost wholly dependent on evidence from documentary sources, since very few archaeobotanical studies had been undertaken at that date. However, the potential contribution of archaeobotanical research to this topic was highlighted early on. For example, in a review of Watson's (1983) book, Johns (1984:344) observed:

"The hypothesis of an…agricultural revolution is challenging and may well prove useful. It will certainly stimulate debate as present and future archaeological and palaeobotanical research yields new evidence."

With the growth of medieval, or Islamic archaeology, and the increasing application of archaeobotanical research across the Mediterranean and Middle East, new perspectives on the concept of an Islamic agricultural revolution are beginning to emerge, highlighting a broadly medieval, or Islamic, timeframe for the diffusion of new crops (cf. Boivin et al. 2014). At present, the best evidence for the diffusion of new crops and cultivars comes from Quseir al-Qadim, a port situated on the Indian Ocean coast in Egypt where both Roman (1st-3rd centuries) and Islamic

(11th-13th, 14th-15th centuries) evidence has been recovered (van der Veen 2011). At this site, desiccated preservation of archaeobotanical remains points towards the introduction of new crops in the Islamic period – sugarcane, taro, aubergine, lime and banana – whilst other crops became more widely cultivated – sorghum, pearl millet, cotton, rice, citrus fruits. Evidence for the diffusion of new cultivars was also identified, in this case the watermelon, a crop already present in the Roman and earlier periods (cf. Paris 2015), yet by the Islamic period, a different cultivar was introduced. The overall impression given by the evidence from Quseir al-Qadim is of a profound reorientation in agriculture, diets and foodways away from a Mediterranean focus in the Roman period to one that looked increasingly towards the east in the Islamic period. In the case of Egypt at least, there is compelling evidence to support some of Watson's (1983) claims over the diffusion of new crops, cultivars and farming practices (van der Veen 2011:231).

Elsewhere the situation is less clear, however, recent finds across the Mediterranean and Middle East add to the growing body of archaeobotanical evidence for the diffusion of new crops. For example, in Jerusalem, aubergine has recently been recovered in 8th-10th century contexts (Amichay et al. 2019). Whilst in Sicily, archaeobotanical evidence dating from the Islamic and later medieval periods at Mazara del Vallo has recorded citrus fruits in the 10th century, watermelon, aubergine and cotton in the 11th-12th century, and finally spinach is recorded in the 13th century (Carver et al. 2019). In southern France, spinach has also recently been identified in the 12th-13th century, whilst sorghum is recorded in the 11th-13th centuries (Ruas et al. 2015; Pradat and Ruas 2017). In al-Andalus, a small number of 'new' crops have been identified. Apricot is recorded in a 12th-13th century Islamic context in Mértola, southern Portugal (van Leeuwaarden and Querioz 2003). Citrus fruit seeds from 9th-11th century contexts have also been recently recovered from Mértola, as well as Lorca in the south-east of Spain (Morales et al. 2019). In Mallorca, at Sa Capellata, a 12th-13th century Islamic context produced watermelon (López and Marlasca 2009). These rare archaeobotanical finds do not prove the 'Watson thesis' *per see*, however, they do allude to the diffusion of new crops within a broadly Islamic, or medieval, timescale. In a recent review article focusing on the 'Watson thesis', Squatriti (2014a:1216) noted that "such unpredictable congruence between current archaeobotany and many of Watson's 1970s findings give hope that the revolution is not over yet."

When we combine this archaeobotanical evidence with what is known from the documentary sources and archaeological analyses of irrigation systems, there were undoubtedly important changes in agriculture following the Islamic conquests. Nevertheless, it is still far from clear how widely new crops, cultivars and farming practices were adopted. The extent to which we identify continuity and contrast in agriculture across this period will in part depend on the analysis of larger archaeobotanical datasets. In particular, the key benefit of archaeobotanical research to this topic is the analysis of a longer-time perspective and a focus on areas not covered by the documentary record, namely the rural early Islamic world. At present, archaeobotanical research is still in its early stages and the evidence is highly fragmentary (van der Veen 2011:111; Wilkinson 2016). Consequently, it is not yet possible fully evaluate the role of Islam in the transmission and innovation of agriculture and the transformation of agrarian landscapes. Nevertheless, the archaeobotanical and crop isotope evidence analysed in this PhD contributes significantly to our understanding of agriculture at the frontier of Islam in the Iberian Peninsula.

Reflecting back on the original themes of this PhD, some key conclusions can be drawn out. In particular, through the study areas examined this PhD challenges the notion of a sweeping agricultural transformation following the Islamic conquests. Instead, a pattern of longer-term continuity is emphasised with more minor adjustments and changes in agriculture through time. In general, we see a gradual increase in crop diversity which reflects broader patterns seen across Europe and the Mediterranean. It is hypothesised that there may have been a divergence in agriculture between rural and urban settings, with documentary sources and archaeobotanical evidence hinting at the cultivation of a different crops in these areas during the Islamic period. Shifts in the nature of farming practices (e.g. irrigation) and in the organisation and management of agriculture (e.g. modes of production) were potentially more significant, although the reflection of these in the archaeobotanical record is relatively slight at present. However, at the same time, the archaeobotanical record draws attention to a different picture of agriculture, contrasting with the idea of a sweeping agricultural transformation suggested by documentary sources. Consequently, it is suggested that a more holistic understanding of changes in agriculture can be developed by interweaving evidence from both archaeobotanical and documentary evidence.

6.1 Avenues for future research

The results of this PhD highlight a number of areas where future research could provide new insights into agriculture:

- **Further integration between the archaeobotanical and archaeological evidence**. There is a long tradition of analysing cultivated spaces, especially irrigated areas, in medieval Iberia through so-called 'hydraulic archaeology'. Such research provides valuable information on the nature, organisation and design of these areas, yet a key line of evidence missing is direct evidence for the crops themselves. Archaeobotanical and crop isotope evidence can help to fill this gap. In the case of the Huecha Valley, the results from this PhD could be combined with those from the ongoing Moncayo Archaeological Survey (MAS). This could involve the mapping of pottery scatters to help identify diachronic patterns of land-use, especially the manuring of irrigated fields (cf. Forbes 2013). Similarly, the results could be combined in greater detail with the survey and the irrigation system and field terraces (cf. Gerrard 2011). Of key importance here would be the direct OSL dating of *acequias* and terraces (cf. Bailiff et al. 2015). Through the combination of these approaches, it would in effect be possible to map the archaeobotanical evidence onto the landscape. A similar approach to this has been undertaken for the Islamic city of Tortosa (Kirchner et al. 2014).

- Primary documentary research. For the later medieval period an extensive body of documentary evidence exists and this PhD has only scraped the surface of this material. It has been beyond the scope of this PhD to undertake a comprehensive review of these documents which would, in part, require new archival research. There are two principal areas where the evidence from these documentary sources can provide valuable information. Firstly, documents produced immediately following the Christian conquests may shed light on the range of crops cultivated in the preceding Islamic period. Similar approaches to this have been undertaken in other areas of al-Andalus (e.g. Trillo San José 2004; Kirchner et al. 2014; Kirchner 2018). Secondly, the documentary evidence would add more nuance to our understanding of the range of crops cultivated during the later medieval period. This could form a key component of discussions over the transition from an 'Islamic' agricultural system to a later medieval or feudal one. The degree of continuity between these two periods a key aspect of research in Iberia.

- Charcoal analysis. It was beyond the scope of this PhD to undertake the analysis of charcoal, which could in itself be another project. Charcoal could help to corroborate the picture presented by the analysis of the archaeobotanical dataset, providing valuable evidence for arboriculture and viticulture. In particular, charcoal may better reflect local cultivation since the seeds from dried fruits (e.g. figs, raisins) recovered in archaeobotanical assemblages could reflect traded items. Methodologically, Terral and Durand (2006) also highlight that it may be possible to distinguish between irrigated and rainfed olives through charcoal anatomy. It has generally been thought there was an expansion in irrigated arboriculture following the Islamic conquests (e.g. Glick 2005:72-

75) and the application of this methodological approach could provide an insight into this.

- **Stable carbon ($\delta^{13}C$), nitrogen ($\delta^{15}N$) and sulphur ($\delta^{34}S$) isotope analysis of plant remains**. There is significant potential in expanding the use of the stable isotopes of carbon, nitrogen and sulphur to investigate in greater detail agriculture and patterns of land-use. As this PhD has demonstrated, stable carbon isotope analysis of cereal grains, rachises and pulse seeds can provide a valuable insight into irrigated and rainfed agriculture. This approach could also be extended to remains of fruits (e.g. grape, fig, walnut) and there is a methodological basis for this (see, for example, de Souza et al. (2005) and Gómez-Alonso et al. (2010) on carbon isotopes in grape vines). The use of nitrogen isotopes to investigate manuring in cereals and pulses is well-established and this could also be undertaken for the samples analysed in the PhD (Bogaard et al. 2007; Fraser et al. 2011). For example, it is likely that rainfed cereals received no manure, whilst irrigated cereals could have been manured (cf. Watson 1983:125). However, the interpretation of plant nitrogen isotope values in Mediterranean regions can be complicated by aridity (and salinity) which can significantly increase $\delta^{15}N$ values (Styring et al. 2016a; Bogaard et al. 2018). Finally, sulphur isotopes may provide evidence for crop provenance and cultivation in different areas of the landscape since they are (in part) influenced by geology and soil conditions (Nitsch et al. 2019b). For example, in the present-day Huecha Valley, irrigated agriculture is primarily undertaken within areas of Quaternary river terrace deposits, whilst rainfed cereal cultivation predominates in areas of Tertiary sedimentary geology. The cultivation of crops in these different areas may be distinguishable using sulphur isotope analysis, especially when combined with carbon isotope analysis to identify irrigated/rainfed cultivation. Ultimately, applying a multi-isotope approach in conjunction with evidence from arable weeds could allow greater discrimination of changes in agriculture.

- **Further archaeobotanical research**. The most obvious and pressing requirement is for further archaeobotanical research to be undertaken. In the first instance, the sampling of a wider range of sites in the Huecha Valley would cover some of the gaps in the current evidence. In particular, evidence from Roman sites, early Islamic sites (8th-10th century) and sites immediately post-dating the Christian conquest (c.12th century). The approach adopted in this PhD highlights the potentially rich archaeobotanical datasets which can be obtained from multiple, small-scale excavations (cf. Rippon et al. 2014:216). Secondly, research in different areas of Iberia would provide a valuable comparison to the evidence analysed for this PhD. Given the widely varying climate and geography of the Iberian Peninsula, the development of agriculture in different regions no doubt also differed. For example, archaeobotanical research in the south of the peninsula with its milder climate (and even sub-tropical climate in some coastal areas) might be expected to produce the best evidence for the introduction of new crops in the Islamic period. Certainly, the documentary sources allude to the introduction of new crops in the south (e.g. Martínez Enamorado 2003:114-116). The priority contexts for identifying the introduction of new crops would in the first case be waterlogged deposits. Whilst waterlogged deposits are very rare, they might be expected to occur in wells and cities, especially those in coastal locations (cf. Pérez-Jordà et al. 2017). The few waterlogged deposits sampled to date in Iberia have revealed a great diversity of remains (e.g. Rua dos Correiros: Bugalhâo and Queiroz 2005, Banco de España: Teira Brión 2015). Secondly, cesspits/latrines with mineralised preservation also hold significant potential, particularly in charting changes in diets and the introduction of new fruit species (cf. Greig 1996; Amichay et al. 2019). In comparison, charred archaeobotanical assemblages provide the best indication of the arable component of economies (van der Veen 2007).

Bibliography

Abad Asensio, J.M. 2006. Algunas ordenanzas medievales de la Comunidad de aldeas de Teruel. Aragón en la Edad Media 19: 25-38.

Acién Almansa, M. 1999. Poblamiento indígena en al-Andalus e indicios del primer poblamiento andalusí. Al-Qanṭara 20: 47-64.

Acién Almansa, M. and Manzano Moreno, E. 2009. Organización social y administración política en Al-Ándalus bajo el emirate. Territorio, Sociedad y Poder 2: 331-348.

Acién Almansa, M.P. 2008. Poblamiento y sociedad en el al-Andalus: un mundo de ciudades, alquerías y husun, pp.141-168 in Iglesia Duarte, J.I. (ed.), Cristiandad e Islam en la Edad Media hispana: XVIII Semana de Estudios Medievales, Nájera, del 30 de julio al 3 de agosto de 2007. Logroño: Instituto de Estudios Riojanos

Agencia Estatal de Meteorología [AEMET] (2019). Visor del Atlas climático de la Península y Baleares, 1971-2000. Madrid: Agencia Estatal de Meteorología. Available at: http://agroclimap.aemet.es.

Aguilera, I. 2014. Un capitel visigodo hallado en la iglesia de San Bartolomé de Borja (Zaragoza). Cuadernos de Estudios Borjanos 17: 13-34.

Aguilera, M., Araus, J.L., Voltas, J., Rodríguez-Ariza, M.O., Molina, F., Rovira, N., Buxó, R. and Ferrio, J.P. 2008. Stable carbon and nitrogen isotopes and quality traits of fossil cereal grains provide clues on sustainability at the beginnings of Mediterranean agriculture. Rapid Communications in Mass Spectrometry 22: 1653-1663.

Aguilera, M., Zech-Matterne, V., Lepetz, S. and Balasse, M. 2018. Crop fertility conditions in North-Eastern Gaul during the La Tène and Roman periods: a combined stable isotope analysis of archaeobotanical and archaeozoological remains. Environmental Archaeology 23: 323-337.

Ainaga Andrés, M.T. 1987. Rentas del obispo de Tarazona en el año 1389. Aragón en la Edad Media 7: 57-80.

Alagich, R., Gardeisen, A., Alonso, N., Rovira, N. and Bogaard, A. 2018. Using stable isotopes and functional weed ecology to explore social differences in early urban contexts: The case of Lattara in Mediterranean France. Journal of Archaeological Science 93: 135-149.

Albertini, L. 2013. Essor de l'agriculture en al-Andalus, Ibérie arabe: Xe-XIVe siècle: performances des agronomes arabo-andalous. Paris: l'Harmattan.

Alcolea, M, Tarongi, M and Aguilera, I. 2018. Estudio arqueobotánico de la Cueva de Majadalares II (Tarazona, Zaragoza). Congreso Nacional de Arqueología Profesional, 525-533. Zaragoza.

Alcolea, M. and Rodanés, J.M. 2019. Ephemeral archaeology south of the central Pyrenees (Huesca, NE Iberia): the exceptional preservation of woody objects in Moro de Alins cave-site. Environmental Archaeology, DOI: 10.1080/14614103.2019.1654642.

Alexander, M.M., Gutiérrez, A., Millard, A.R., Richards, M.P. and Gerrard, C.M., 2019. Economic and socio-cultural consequences of changing political rule on human and faunal diets in medieval Valencia (c.fifth–fifteenth century AD) as evidenced by stable isotopes. Archaeological and Anthropological Sciences 11: 3875-3893.

Alonso, N. 2005. Agriculture and food from the Roman to the Islamic Period in the North-East of the Iberian Peninsula: archaeobotanical studies in the city of Lleida (Cataluña, Spain). Vegetation History and Archaeobotany 14: 341-361

Alonso, N. 2008. Crops and agriculture during the Iron Age and late antiquity in Cerdanyola del Vallès (Cataluña, Spain). Vegetation History and Archaeobotany 17: 75-84.

Alonso, N., 2000. Cultivos y producción agrícola en época ibérica. Segvntvm 3: 25-46.

Alonso, N., Junyent, E., Lafuente, A. and López, J.B. 2008. Plant remains, storage and crop processing inside the Iron Age fort of Els Vilars d'Arbeca (Catalonia, Spain). Vegetation History and Archaeobotany 17: 149-158.

Alonso, N., Antolín, F. and Kirchner, H. 2014a. Novelties and legacies in crops of the Islamic period in the northeast Iberian Peninsula: The archaeobotanical evidence in Madîna Balagî, Madîna Lârida, and Madîna Turṭûša. Quaternary International 346: 149-161.

Alonso, N., Cantero, F.J., Jornet, R., López, D., Montes, E., Prats, G. and Valenzuela, S. 2014b. Milling wheat and barley with rotary querns: the Ouarten women (Dahmani, Kef, Tunisia). AmS-Skrifter, 24, pp.11-30 L. Selsing (ed.), Seen through a Millstone: Geology and Archaeology of Quarries and Mills. Bergen: Museum of Archaeology, University of Stavanger.

Alonso, N., Cantero, F.J., López, D., Montes, E., Prats, G., Valenzuela-Lamas, S. and Jornet, R. 2017. Etnoarqueología de la basura: almacenaje en silos y su reaprovechamiento en la población Ouarten de El Souidat (El Kef, Túnez), pp.38-61 in J. Fernández Eraso, J. Mujika Alustiza, A. Arrizabalaga Valbuena and M. García Diez (eds.) Miscelánea en homenaje a Lydia Zapata Peña (1965-2015). Bilbao: Universidad del País Vasco.

Amichay, O., Ben-Amim D., Tchekhanovets, Y., Shahack-Gross, R., Fuks, D. and Weiss, E. 2019. A bazaar assemblage: reconstructing consumption, production and trade from mineralised seeds in Abbasid Jerusalem. Antiquity 93: 197-217.

Anderson, G.D. 2013. The Islamic Villa in Early Medieval Iberia: Architecture and Court Culture in Umayyad Córdoba. Surrey: Ashgate Publishing.

Anyia, A.O., Slaski, J.J., Nyachiro, J.M., Archambault, D.J. and Juskiw, P. 2007. Relationship of carbon isotope discrimination to water use efficiency and productivity of barley under field and greenhouse conditions. Journal of Agronomy and Crop Science 193: 313-323.

Araus, J.L. and Buxó, R. 1993. Changes in carbon isotope discrimination in grain cereals from the north-western Mediterranean basin during the past seven millennia. Australian Journal of Plant Physiology 20: 117-128.

Araus, J.L., Febrero, A., Buxó, R., Rodrıguez-Ariza, M.O., Molina, F., Camalich, M.D., Martın, D. and Voltas, J. 1997a. Identification of ancient irrigation practices based on the carbon isotope discrimination of plant seeds: a case study from the South-East Iberian Peninsula. Journal of Archaeological Science 24: 729-740.

Araus, J.L., Febrero, A., Buxó, R., Camalich, M.D., Martín, D., Molina, F., Rodríguez-Ariza, M.O. and Romagosa, I. 1997b. Changes in carbon isotope discrimination in grain cereals from different regions of the western Mediterranean Basin during the past seven millennia. Palaeoenvironmental evidence of a differential change in aridity during the late Holocene. Global Change Biology 3: 107-118.

Araus, J.L., Febrero, A., Catala, M., Molist, M., Voltas, J. and Romagosa, A.I. 1999. Crop water availability in early agriculture: evidence from carbon isotope discrimination of seeds from a tenth millennium BP site on the Euphrates. Global Change Biology 5: 201-212.

Araus, J.L., Ferrio, J.P., Buxó, R. and Voltas, J. 2006. The historical perspective of dryland agriculture: lessons learned from 10 000 years of wheat cultivation. Journal of Experimental Botany 58: 131-145.

Araus, J.L., Ferrio, J.P., Buxó, R. and Voltas, J. 2007. The historical perspective of dryland agriculture: lessons learned from 10 000 years of wheat cultivation. Journal of Experimental Botany 58: 131-145.

Araus, J.L., Ferrio, J.P., Voltas, J., Aguilera, M. and Buxó, R. 2014. Agronomic conditions and crop evolution in ancient Near East agriculture. Nature Communications 5: 3953.

Araus, J.L., Villegas, D., Aparicio, N., Del Moral, L.F., El Hani, S., Rharrabti, Y., Ferrio, J.P. and Royo, C., 2003. Environmental factors determining carbon isotope discrimination and yield in durum wheat under Mediterranean conditions. Crop Science 43: 170-180.

Arié, R. 1982. España musulmana (siglos VIII-XV). Barcelona: Labor.

Ashmore, P.J. 1999. Radiocarbon dating: avoiding errors by avoiding mixed samples. Antiquity 73: 124-130.

Assis, Y.T. 1997. Jewish economy in the medieval crown of Aragon, 1213-1327: money and power. New York: Brill.

Aubaile Sallenave, F. 1984. L'agriculture musulmane aux premiers temps de la conquête: apports et emprunts; à propos de Agricultural innovation in the early Islamic world de Andrew M. Watson. Journal d'Agriculture Traditionnelle et de Botanique Appliquée 31:245-256.

Aubaile Sallenave, F. 2012. Pathways of diffusion of some plants and animals between Asia and the Mediterranean region. Revue d'ethnoécologie 1.

Badura, M., Możejko, B. and Ossowski, W. 2013. Bulbs of onion (*Allium cepa* L.) and garlic (*Allium sativum* L.) from the 15th-century Copper Wreck in Gdańsk (Baltic Sea): a part of victualling?. Journal of Archaeological Science 40: 4066-4072.

Bailiff, I.K., Gerrard, C.M., Gutiérrez, A., Snape-Kennedy, L.M. and Wilkinson, K.N. 2015. Luminescence dating of irrigation systems: Application to a qanat in Aragón, Spain. Quaternary Geochronology 30: 452-459.

Bailiff, I.K., Jankowski, N., Gerrard, C.M., Gutiérrez, A. and Wilkinson, K.N. 2019. Luminescence dating of sediment mounds associated with shaft and gallery irrigation systems. Journal of Arid Environments 165: 34-45.

Bakels, C. and Jacomet, S. 2003. Access to luxury foods in Central Europe during the Roman period: the archaeobotanical evidence. World Archaeology 34: 542-557.

Barceló, M. 1985. Un estudio sobre la estructura fiscal y procedimientos contables del Emirato Omeya de Córdoba (138-300/755-912) y del Califato (300-366/912-976). Acta Historica et Archaeologica Mediaevalia 5-6: 45-72.

Barceló, M. 1989. El diseño de espacios irrigados en al-Andalus: un enunciado de principios generals, pp.15-70 in L. Cara Barrionuevo (ed.), El agua en zonas áridas. Arqueología e historia.

Hidráulica tradicional de la provincia de Almería. Almería: Instituto de Estudios Almerienses de la Diputación de Almería.

Barceló, M. 1995. Saber lo que es un espacio hidráulico y lo que no es o al-Andalus y los feudales, pp.240-254 in J. González Alcantud and A Malpica Cuello (eds.), El agua, mitos, ritos y realidades: coloquio internacional, Granada, 23-26 de noviembre de 1992. Granada: Diputación Provincial de Granada.

Barceló, M. 1996. La cuestión del hidraulismo andalusí, pp.11-47 in M. Barceló, H. Kirchner and C. Navarro (eds.) El agua que no duerme. Fundamentos de la arqueología hidráulica andalusí. Granada: Legado Andalusí.

Barney, S.A., Lewis, W.J., Beach, J.A. and Berghof, O. 2006. The etymologies of Isidore of Seville. Cambridge University Press.

Barreiro-Lostres, F., Moreno, A., Giralt, S., Caballero, M. and Valero-Garcés, B. 2014. Climate, palaeohydrology and land use change in the Central Iberian Range over the last 1.6 kyr: The La Parra Lake record. The Holocene 24: 1177-1192.

Barriendos, M., Gil-Guirado, S., Pino, D., Tuset, J., Pérez-Morales, A., Alberola, A., Costa, J., Balasch, J.C., Castelltort, X., Mazón, J. and Ruiz-Bellet, J.L. 2019. Climatic and social factors behind the Spanish Mediterranean flood event chronologies from documentary sources (14th–20th centuries). Global and Planetary Change 182: 102997.

Bazzana, A. and Guichard, P. 1981. Irrigation et société dans l'Espagne orientale au Moyen Age, pp.115-140 in J. Metral and P. Sanlaville (eds.) L'Homme et l'eau en Mediterranée et au Proche Orient. Lyon: Travaux de la Maison de l'Orient.

Bazzana, A., Cressier, P. and Guichard, P. 1988. Les châteaux ruraux d'al-Andalus: histoire et archéologie des Ḥuṣūn du sud-est de l'Espagne. Madrid: Casa de Velázquez.

Behre, K.E. 1992. The history of rye cultivation in Europe. Vegetation History and Archaeobotany 1: 141-156.

Behre, K-E. and Jacomet, S. 1991. The ecological interpretation of archaeobotanical data, pp.81-108 in W. van Zeist, K. Wasylikowa and K. Behre (eds.), Progress in Old World Palaeoethnobotany. Rotterdam: Balkema.

Bergmann, W. 1940. Relations between the food and silk of silkworms. Textile Research 10: 462-475.

Berihuete-Azorín, M., Stika, H.P., Bourliva, A., Papadopoulou, L. and Valamoti, S.M. 2019. "Fresh from the Oven": experiments on *Triticum spelta* and a protocol for carbonising specimens for archaeobotanical comparison collections. Journal of Archaeological Science: Reports 26:101865.

Bertrán Roigé, P. 2013. La alimentación de pobres y peregrinos en la Cataluña medieval, pp.43-64 in M. García Guatas, E. Piedrafita and J. Barbacil (eds.) La alimentación en la Corona de Aragón (siglos XIV-XV). Zaragoza: Institución Fernando el Católico

Blanco Morte, A. 2007. Informe final de la actuación de seguimiento y control arqueológico de las obras de restauración y excavación arqueológicia en la Iglesia Parroquial de San Miguel de Ambel (Zaragoza). N. Exp. 408/2007. Unpublished Report.

Blondel, J., Aronson, J., Bodiou, J-Y. and Boeuf, G. 2010. The Mediterranean region: biological diversity through time and space. Oxford: Oxford University Press.

Boardman, S. and Jones, G. 1990. Experiments on the effects of charring on cereal plant components. Journal of Archaeological Science 17: 1-11.

Bogaard, A. 2004. Neolithic farming in central Europe: an archaeobotanical study of crop husbandry practices. London: Routledge.

Bogaard, A. 2016. Archaeobotany: The wheat and the chaff. Nature Plants 2: 16079.

Bogaard, A., Charles, M., Livarda, A., Ergun, M., Filipović, D. and Jones, G. 2013a. The archaeobotany of mid-later Neolithic occupation levels at Çatalhöyük, pp.93-128 in I. Hodder (ed.), Humans and landscapes of Çatalhöyük: reports from the 2000-2008 seasons. Los Angeles/London, Cotsen Institute of Archaeology/British Institute at Ankara.

Bogaard, A., Fraser, R., Heaton, T.H., Wallace, M., Vaiglova, P., Charles, M., Jones, G., Evershed, R.P., Styring, A.K., Andersen, N.H. and Arbogast, R.M. 2013b. Crop manuring and intensive land management by Europe's first farmers. Proceedings of the National Academy of Sciences 110: 12589-12594.

Bogaard, A., Heaton, T.H., Poulton, P. and Merbach, I. 2007. The impact of manuring on nitrogen isotope ratios in cereals: archaeological implications for reconstruction of diet and crop management practices. Journal of Archaeological Science 34: 335-343.

Bogaard, A., Hodgson, J., Nitsch, E., Jones, G., Styring, A., Diffey, C., Pouncett, J., Herbig, C., Charles, M., Ertuğ, F. and Tugay, O. 2016. Combining functional weed ecology and crop stable isotope ratios to identify cultivation intensity: a comparison of cereal production regimes in Haute Provence, France and Asturias, Spain. Vegetation History and Archaeobotany 25: 57-73.

Bogaard, A., Jones, G. and Charles, M. 2005. The impact of crop processing on the reconstruction of crop sowing time and cultivation intensity from archaeobotanical weed evidence. Vegetation History and Archaeobotany 14: 505-509.

Bogaard, A., Jones, G., Charles, M. and Hodgson, J.G. 2001. On the archaeobotanical inference of crop sowing time using the FIBS method. Journal of Archaeological Science 28: 1171-1183.

Bogaard, A., Palmer, C., Jones, G., Charles, M. and Hodgson, J.G. 1999. A FIBS approach to the use of weed ecology for the archaeobotanical recognition of crop rotation regimes. Journal of Archaeological Science 26: 1211-1224.

Bogaard, A., Styring, A., Ater, M., Hmimsa, Y., Green, L., Stroud, E., Whitlam, J., Diffey, C., Nitsch, E., Charles, M. and Jones, G. 2018. From traditional farming in Morocco to early urban agroecology in northern Mesopotamia: combining present-day arable weed surveys and crop isotope analysis to reconstruct past agrosystems in (semi-) arid regions. Environmental Archaeology 23: 303-322.

Boivin, N. 2017. Proto-globalisation and biotic exchange in the Old World, pp.349-408 in N. Boivin (ed.), Human Dispersal and Species Movement: From Prehistory to the Present. Cambridge: Cambridge University Press.

Boivin, N., Crowther, A., Prendergast, M. and Fuller, D.Q. 2014. Indian Ocean food globalisation and Africa. African Archaeological Review 31: 547-581.

Boivin, N., Fuller, D.Q. and Crowther, A. 2012. Old World Globalization and the Columbian Exchange: Comparison and Contrast. World Archaeology 44: 452-469.

Bolens, L. 1972. L'eau et l'irrigation d'apres les traits d'agronomie andalous au Moyen-Age (XIe-XIIe siecles). Options Mediterrane'nnes 16: 64-77.

Bolens, L. 1977. La greffe et les métamorphoses du jardin andalou au Moyen Age (XIe-XIIe siècles). Études Rurales 68: 93-106.

Bolens, L. 1978. La Révolution agricole andalouse du XIe siècle. Studia Islamica 47:121-141.

Bolens, L. 1980. Pain quotidien et pains de disette dans l'Espagne musulmane. Annales: Histoire, Sciences Sociales 35: 462-476.

Bolens, L. 1981. Agronomes Andalous du Moyen-Age. Geneva-Paris: Droz.

Bolòs, J. 1993. Paisatge i societat al "Segrià" al segle XIII, pp.45-81 in J. Bolòs (ed.), Paisatge i societat a la Plana de Lleida a l'edat mitjana. Lleida: Universitat de Lleida.

Bolòs, J. 2001. Changes and survival: the territory of Lleida (Catalonia) after the twelfth-century conquest. Journal of Medieval History 27: 313-329.

Bolòs, J., 2009. Landscape formation in a Mediterranean country of the Middle Ages. Changes and continuity in Catalonia between the sixth and the fifteenth century. Landscape History 30: 21-36.

Bolós, O., Vigo, J., Masalles, R. and Ninot, J.M. 2005. Flora manual dels Països Catalans. Barcelona: Pòrtic Edicions.

Bond, J. and Hunter, J. 1987. Flax-growing in Orkney from the Norse period to the 18th century. Proceedings of the Society of Antiquaries of Scotland 117: 175-181.

Bosch Vilá, J. 1959. Historia de Albarracin y su sierra: Albarracin musulman. Teruel: Instituto de Estudios Turolenses.

Bosch Vilá, J. 1998. Considerations with respect to "*al-Thagr* in al-Andalus" and the political-administrative division of Muslim Spain, pp.347-388 in M. Marín (ed.), The Formation of al-Andalus. Part 1: History and Society. Aldershot: Ashgate.

Bouby, L. 2001. L'orge à deux rangs (Hordeum distichum) dans l'agriculture gallo-romaine: données archéobotaniques. ArchéoSciences 25: 35-44.

Bouby, L., Bonhomme, V., Ivorra, S., Pastor, T., Rovira, N., Tillier, M., Pagnoux, C. and Terral, J.F. 2018. Back from burn out: are experimentally charred grapevine pips too distorted to be characterized using morphometrics? Archaeological and Anthropological Sciences10: 943-954.

Bouby, L., Pradat, B. and Ruas, M.P. 2005. Les restes de fruits dans les dépôts archéologiques du Midi de la France (Ve-XVIe siècles). Archéologie du Midi medieval 23: 145-193.

Bouchaud, C., Tengberg, M. and Dal Prà, P. 2011. Cotton cultivation and textile production in the Arabian Peninsula during antiquity; the evidence from Madâ'in Sâlih (Saudi Arabia) and Qal'at al-Bahrain (Bahrain). Vegetation History and Archaeobotany 20: 405-417.

Bouchette, A., Rösch, M. and Jalut, G. 2011. Paysages, productions et collectes végétales en Limousin (Massif central occidental) de la Tène finale à la fin du Moyen Âge (100 BC-1 400AD). ArcheoSciences. Revue d'archéométrie 35: 65-92.

Braadbaart, F. 2008. Carbonisation and morphological changes in modern dehusked and husked *Triticum dicoccum* and *Triticum aestivum* grains. Vegetation History and Archaeobotany 17: 155-166.

Braadbaart, F. and van Bergen, P.F. 2005. Digital imaging analysis of size and shape of wheat and pea upon heating under anoxic conditions as a function of the temperature. Vegetation History and Archaeobotany 14: 67-75.

Braadbaart, F., Bakels, C.C., Boon, J.J. and van Bergen, P.F. 2005. Heating experiments under anoxic conditions on varieties of wheat. Archaeometry 47: 103-114.

Bramon, D. 2000. De quan érem o no musulmans. Textos del 713 al 1010. Barcelona: Institut d'Estudis Catalans.

Braun-Blanquet, J. and de Bolós, O. 1957. Les groupements végétaux du bassin moyen de l'Ebre et leur dynamisme. Anales de la Estación Experimental de Aula Dei 5: 1-266.

Brett, M. 1985. Reviewed work: Agricultural innovation in the Early Islamic world: the diffusion of crops and farming techniques, 700-1100. Bulletin of the School of Oriental and African Studies 48:126-128.

Brinkkemper, O., Braadbaart, F., van Os, B., Van Hoesel, A., Van Brussel, A.A.N. and Fernandes, R. 2018. Effectiveness of different pre-treatments in recovering pre-burial isotopic ratios of charred plants. Rapid Communications in Mass Spectrometry 32: 251-261.

Brite, E.B. and Marston, J.M. 2013. Environmental change, agricultural innovation, and the spread of cotton agriculture in the Old World. Journal of Anthropological Archaeology 32: 39-53.

Bronk-Ramsey, C. 2013. OxCal 4.2. Oxford: Oxford University Radiocarbon Accelerator Unit.

Brown, T.A., Cappellini, E., Kistler, L., Lister, D.L., Oliveira, H.R., Wales, N. and Schlumbaum, A. 2015. Recent advances in ancient DNA research and their implications for archaeobotany. Vegetation History and Archaeobotany 24: 207-214.

Brufal, J. 2017. The northeast of the Iberian Peninsula and its Muslim rulers (eighth-twelfth century), pp.37-69 in F. Sabaté (ed.), The Crown of Aragon: a singular Mediterranean Empire. Leiden/Boston: Brill.

Bulliet, R.W. 2009. Cotton, Climate and Camels in the Early Islamic Iran: A Moment in World History. New York: Columbia University Press.

Büntgen, U., Krusic, P.J., Verstege, A., Sangüesa-Barreda, G., Wagner, S., Camarero, J.J., Ljungqvist, F.C., Zorita, E., Oppenheimer, C., Konter, O. and Tegel, W. 2017. New tree-ring evidence from the Pyrenees reveals Western Mediterranean climate variability since medieval times. Journal of Climate 30: 5295-5318.

Burger, P., Terral, J.F., Ruas, M.P., Ivorra, S. and Picq, S. 2011. Assessing past agrobiodiversity of *Prunus avium* L. (Rosaceae): a morphometric approach focussed on the stones from the archaeological site Hôtel-Dieu (16th century, Tours, France). *Vegetation History and Archaeobotany* 20: 447-458.

Burns, R.I. 1975. Medieval colonialism: postcrusade exploitation of Islamic Valencia. New Jersey: Princeton University Press.

Butzer, K.W. 1994. The Islamic traditions of agroecology: Crosscultural experience, ideas and innovations. Ecumene 1: 7-50.

Butzer, K.W., Mateu, J.F., Butzer, E.K. and Kraus, P. 1985a. Irrigation agrosystems in eastern Spain: Roman or Islamic origins?. Annals of the Association of American Geographers 75: 479-509.

Butzer, K.W., Butzer, E.K., Miralles, I. and Mateu, J.F. 1985b. Una alquería islamica medieval de la Sierra de Espadán. Boletín de la Sociedad Castellonense de Cultura 61: 305-365.

Buxó, R., Alonso, N., Canal, D., Echave, C. and González, I. 1997. Archaeobotanical remains of hulled and naked cereals in the Iberian Peninsula. Vegetation History and Archaeobotany 6: 5-23.

Cabanes Pecourt, M D. 1987. Los mudéjares de Muzalcoraz y el monasterio de Veruela, datos de una economía en el siglo XII. IV Simposio Internacional de Mudejarismo, 143-150.

Cabanes Pecourt, M.D. 1984. Cartas de población en el dominio verolense. Aragón en la Edad Media 6: 95-124.

Caetano Leitão, M.I. 2018. O Povoamento Rural Islâmico no al-Andalus – Estado da investigação. Anales de Arquelogía Cordobesa 29: 293-318.

Calva Capilla, S. 2011. Les premières mosquées et la transformation des sanctuaires wisigothiques (92H/711-170H/785). Mélanges de la Casa de Velázquez 41: 131-163.

Cámara, L.N. and Aranz, B.M. 1994. La mezquita mayor de Tudela: excavaciones arqueológicas. Revista del Centro de Estudios Merindad de Tudela 6: 5-18.

Cappers, R.T.J. and Neef, R. 2012. Handbook of Plant Palaeoecology. Groningen: Groningen University.

Cappers, R.T.J., Bekker, R.M. and Jans, J.E.A. 2012. Digital seed atlas of the Netherlands (2nd edition). Groningen: Barkhuis.

Cappers, R.T.J., Neef, R. and Bekker, R.M. 2009. Digital atlas of economic plants. Groningen: Barhuis/Groningen University Library.

Carabaza Bravo, J.M., García Sánchez, E., Hernández Bermejo, J.E. and Jiménez Ramírez, A. 2004. Árboles y arbustos de al-Andalus. Madrid: CSIC.

Carruthers, W.J. 1991. Mineralised plant remains: some examples from sites in southern England, pp.75-80 in E. Hajnalová (ed.), Palaeoethnobotany and archaeology: International workgroup for palaeoethnobotany 8th Symposium, Nitra-Nové Vozokany 1989. Nitra: Archaeological Institute of the Slovak Academy of Sciences.

Carvajal, J.C. 2014. The archaeology of al-Andalus: past, present and future. Medieval Archaeology 58: 318-339.

Carver, M.O.H., Molinari, A., Aniceti, V., Capelli, C., Colangeli, F., Drieu, L., Fiorentino, G., Giovannini, F., Hummler, M., Lundy, J.L. and Meo, A., Monnereau, A., Orecchioni, P., Primavera, M. and Ughi, A. 2019. Sicily in transition: new research on early medieval Sicily, 2017-2018. Fasti Online Documents & Research. Available at: www.fastionline.org/docs/FOLDER-it-2019-437.pdf

Castiglioni, E. and Rottoli, M. 2013. Broomcorn millet, foxtail millet and sorghum in north Italian Early Medieval sites. Post-Classical Archaeologies 3: 131-144.

Castro, P.V., Chapman, R.W., Gili, S., Lull, V., Micó, R., Rihuete, C., Risch, R. and Sanahuja, M.E. 1999. Agricultural production and social change in the Bronze Age of southeast Spain: the Gatas Project. Antiquity 73: 846-856.

Castroviejo, S (ed.) 1986-2014. Flora Iberica. Madrid: CSIC.

Catlos, B. 2002. The Ebro Valley and Valencia: Mudéjar experiences related, distinct. Revista d'Historia Medieval 12: 299-312.

Catlos, B. 2004. The Victors and the Vanquished: Christians and Muslims of Catalonia and Aragon 1050-1300. Cambridge: Cambridge University Press.

Catlos, B. 2014. Muslims of Medieval Latin Christendom, c.1050–1614. Cambridge: Cambridge University Press.

Catlos, B. 2018. Kingdoms of Faith: A New History of Islamic Spain. London: Hurst and Company.

Cernusak, L.A., Ubierna, N., Winter, K., Holtum, J.A., Marshall, J.D. and Farquhar, G.D. 2013. Environmental and physiological determinants of carbon isotope discrimination in terrestrial plants. New Phytologist 200: 950-965.

Cervera Fras, M.J. 1989. Conquista y ocupación musulmana, pp.117-124 in Ubieto Arteta, A. (ed.) Historia de Aragón. Zaragoza: Anubar.

Chapman, R.W. 1978. The evidence for prehistoric water control in south-east Spain. Journal of Arid Environments 1: 261-274.

Charles, M. 1984. Introductory remarks on the cereals. Bulletin on Sumerian Agriculture 1: 17-31

Charles, M. 1998. Fodder from dung: the recognition and interpretation of dung-derived plant material from archaeological sites. Environmental Archaeology 1: 111-122.

Charles, M. and Hoppé, C. 2003. The effects of irrigation on the weed floras of winter cereal crops in Wadi Ibn Hamad (Southern Jordan). Levant 35:213-230.

Charles, M., Hoppé, C., Jones, G., Bogaard, A. and Hodgson, J.G. 2003. Using weed functional attributes for the identification of irrigation regimes in Jordan. Journal of Archaeological Science 30: 1429-1441.

Charles, M., Crowther, A., Ertug, F., Herbig, C., Jones, G., Kutterer, J., Longford, C., Madella, M., Maier, U., Out, W., Pessin, H. and Zurro, D. 2009. Archaeobotanical Online Tutorial <http://archaeobotany.dept.shef.ac.uk/>. Accessed: 25-08-2019.

Charles, M., Forster, E., Wallace, M. and Jones, G. 2015. "Nor ever lightning char thy grain": establishing archaeologically relevant charring conditions and their effect on glume wheat grain morphology. STAR 1.

Charles, M., Jones, G. and Hodgson, J.G. 1997. FIBS in archaeobotany: functional interpretation of weed floras in relation to husbandry practices. Journal of Archaeological Science 24: 1151-1161.

Chaves, M.M., Pereira, J.S., Maroco, J., Rodrigues, M.L., Ricardo, C.P.P., Osório, M.L., Carvalho, I., Faria, T. and Pinheiro, C. 2002. How plants cope with water stress in the field? Photosynthesis and growth. Annals of Botany 89: 907-916.

Christys, A. 2002. Christians in al-Andalus 711-1000. Richmond: Curzon Press.

Cirujeda, A., Aibar, J. and Zaragoza, C. 2011. Remarkable changes of weed species in Spanish cereal fields from 1976 to 2007. Agronomy for Sustainable Development 31: 675-688.

Collins, R. 2004. Visigothic Spain, 409-711. Oxford: Blackwell.

Collins, R. 2014. Caliphs and Kings: Spain, 796-1031. Chichester: Wiley Blackwell.

Comet, G. 1992. Le Paysan et son outil. Essai d'histoire technique des céréales (France, VIIIe - XVe siècle). Rome: Ecole française de Rome.

Comet, G. 2004. Les céréales du basempire au moyen âge, pp.131-177 in M. Barceló and F. Sigaut (eds.), The makings of feudal agricultures?. Leiden: Brill.

Condon, A.G., Richards, R.A. and Farquhar, G.D. 1992. The effect of variation in soil water availability, vapour pressure deficit and nitrogen nutrition on carbon isotope discrimination in wheat. Australian Journal of Agricultural Research 43: 935-947.

Constable, O.R. 2013. Food and Meaning: Christian Understandings of Muslim Food and Foodways in Spain, 1250-1550. Viator 44: 199-235.

Constable, O.R. 2018. To live like a moor: Christian perceptions of Muslim identity in medieval and early modern Spain. Philadelphia: University of Pennsylvania Press.

Cook, B.I., Anchukaitis, K.J., Touchan, R., Meko, D.M. and Cook, E.R. 2016. Spatiotemporal drought variability in the Mediterranean over the last 900 years. Journal of Geophysical Research: Atmospheres 121: 2060-2074.

Corella, J.P., Stefanova, V., El Anjoumi, A., Rico, E., Giralt, S., Moreno, A., Plata-Montero, A. and Valero-Garcés, B.L. 2013. A 2500-year multi-proxy reconstruction of climate change and human activities in northern Spain: The Lake Arreo record. Palaeogeography, Palaeoclimatology, Palaeoecology, 386: 555-568.

Corral Lafuente, J.L. 1981. El obispado de Tarazona en el siglo XIV, II: Las propiedades episcopales. Turiaso 2: 205-287.

Corral Lafuente, J.L. 1983. Cambios estructurales en Aragón a mediados del siglo XIII. Aragón en la Edad Media 5: 95-112.

Corral Lafuente, J.L. 1992. La edad media en las comarcas Aragonesas del Moncayo. Turiaso 10: 129-162.

Corral Lafuente, J.L. 1999. El proceso de represión contra los mudéjares aragoneses. Aragón en la Edad Media 14–15: 341-359.

Corral Lafuente, J.L. and Escribano Sánchez, J.C. 1980. El obispado de Tarazona en el siglo XIV: El libro chantre: I, Documentación. Turiaso 1: 11-153.

Coulon, D. 2001. El comercio Catalán del azúcar en el siglo xiv. Anuario de Estudios Medievales 31: 727-756.

Craufurd, P.Q., Austin, R.B., Acevedo, E. and Hall, M.A. 1991. Carbon isotope discrimination and grain-yield in barley. Field Crops Research 27: 301-313.

Cuadrat, J.M., Saz, M.A. and Vicente-Serrano, S.M. 2007. Atlas climático de Aragón. Zaragoza: Gobierno de Aragón.

Cuchí Oterino, J.A. 2005. Nota sobre acerollas y nísperos cultivados en la huerta de Huesca, a partir de una antigua cita. Lucas Mallada: revista de ciencias 12: 145-151.

Dawson, T.E., Mambelli, S., Plamboeck, A.H., Templer, P.H. and Tu, K.P. 2002. Stable isotopes in plant ecology. Annual Review of Ecology and Systematics 33: 507-559.

de Souza, C.R., Maroco, J.P., dos Santos, T.P., Rodrigues, M.L., Lopes, C.M., Pereira, J.S. and Chaves, M.M. 2005. Impact of deficit irrigation on water use efficiency and carbon isotope composition ($\delta^{13}C$) of field-grown grapevines under Mediterranean climate. Journal of Experimental Botany 56:2163-2172.

Decker, M. 2009. Plants and progress: rethinking the Islamic agricultural revolution. Journal of World History20:187-206.

Decker, M. 2011. Tilling the Hateful Earth: Agricultural Production and Trade in the Late Antique East. Oxford: Oxford University Press.

Delgado, M.C.J. and Guerrero, I.C. 2006. Earth building in Spain. Construction and Building Materials 20: 679-690.

Derreumaux, M. 2005. How to detect fodder and litter? A case study from the Roman site Le Marais de Dourges, France. Vegetation History and Archaeobotany 14: 373-385.

Diarte-Blasco, P. 2018. Late antique and early medieval Hispania: landscapes without strategy? An archaeological approach. Oxford: Oxbow Books.

Diefendorf, A.F., Mueller, K.E., Wing, S.L., Koch, P.L. and Freeman, K.H. 2010. Global patterns in leaf ^{13}C discrimination and implications for studies of past and future climate. Proceedings of the National Academy of Sciences 107: 5738-5743.

Djamali, M., Ponel, P., Andrieu-Ponel, V., de Beaulieu, J.L., Guibal, F., Miller, N.F., Ramezani, E., Berberian, M., Lahijani, H. and Lak, R. 2010. Notes on arboricultural and agricultural practices in ancient Iran based on new pollen evidence. Paléorient 36: 175-188.

Domínguez Rojas, S.M. 2006. La economía del reino nazarí a través de las fetuas recogidas en el Mi'yar de Al-Wansarisi. Anaquel de Estudios Árabes 17: 77-108.

Domínguez-Castro, F., de Miguel, J.C., Vaquero, J.M., Gallego, M.C. and García-Herrera, R. 2014. Climatic potential of Islamic chronicles in Iberia: Extreme droughts (AD 711–1010). The Holocene 24: 370-374.

Eiroa Rodríguez, J.A. 2012. Past and present of the archaeology of the alquerías. Imago Temporis 6: 49-72.

El Faïz, M. 2005. Les maîtres de l'eau. Histoire de l'hydraulique arabe. Arles: Actes Sud.

El Faïz, M. 2007. Horticultural changes and political upheavals in Middle-Age Andalusia, pp.115-128 in M. Conan and W.J. Kress (eds.), Botanical Progress, Horticultural Innovation and Cultural Change. Washington: Dumbarton Oaks Research Library and Collection.

Ernst, M. and Jacomet, S. 2006. The value of the archaeobotanical analysis of desiccated plant remains from old buildings: methodological aspects and interpretation of crop weed assemblages. Vegetation History and Archaeobotany 15: 45-56.

Ertuğ, F. 2000. Linseed oil and oil mills in central Turkey Flax/Linum and Eruca, important oil plants of Anatolia. Anatolian Studies 50: 171-185.

Esquilache, F. 2011. L'evolució del paisatge agrari andalusí i feudal de les grans hortes fluvials. Les sèquies de Quart i del Comuner d'Aldaia a l'horta de València. Recerques 62: 5-36.

Falcón, I. 1977. La comercialización del trigo en Zaragoza a mediados del siglo XV. Aragón en la Edad Media 1: 239-273.

Farah, S.M., Arar, A. and Miller, D.E. 1988. Water requirements and the irrigation management of pea, lentil, faba bean and chickpea crops, pp.271-278 in R.J. Summerfield (ed.), World crops: cool season food legumes. Dordecht: Springer.

Farquhar, G.D. 1983. On the nature of carbon isotope discrimination in C4 species. Functional Plant Biology 10: 205-226.

Farquhar, G.D. and Sharkey, T.D. 1982. Stomatal conductance and photosynthesis. Annual Review of Plant Physiology 33: 317-345.

Farquhar, G.D., Ehleringer, J.R. and Hubick, K.T. 1989. Carbon isotope discrimination and photosynthesis. Annual Review of Plant Biology 40: 503-537.

Farquhar, G.D., O'Leary, M.H. and Berry, J.A. 1982. On the relationship between carbon isotope discrimination and the intercellular carbon dioxide concentration in leaves. Functional Plant Biology 9: 121-137.

Febrero, A., Bort, J., Catala, J., Marzabal, P., Voltas, J. and Araus, J.L., 1994. Grain yield, carbon isotope discrimination and mineral content in mature kernels of barley under irrigated and rainfed conditions. Agronomie 2: 127–132.

Fernández Conde, F.J. 2005. La religiosidad medieval en España: Plena Edad Media (siglos XI-XIII). Gijón: Ediciones Trea.

Ferrio, J.P., Araus, J.L., Buxó, R., Voltas, J. and Bort, J. 2005. Water management practices and climate in ancient agriculture: inferences from the stable isotope composition of archaeobotanical remains. Vegetation History and Archaeobotany 14: 510-517.

Ferrio, J.P., Voltas, J., Alonso, N. and Araus, J.L. 2007. Reconstruction of climate and crop conditions in the past based on the carbon isotope signature of archaeobotanical remains. Terrestrial Ecology 1:319-332.

Fierro, M. 2005. 'Abd al-Rahman III: The First Cordoban Caliph. London: Oneworld Publications.

Fierro, M. 2010. The Almohads (524 668/1130 1269) and Hafsids (627 932/1229 – 1526), pp.65-105 in in M. Fierro (ed.), The New Cambridge History of Islam: Volume 2. The Western Islamic World, Eleventh to Eighteenth Centuries. Cambridge: Cambridge University Press.

Fiorentino, G., Caracuta, V., Casiello, G., Longobardi, F. and Sacco, A., 2012. Studying ancient crop provenance: implications from $\delta^{13}C$ and $\delta^{15}N$ values of charred barley in a Middle Bronze Age silo at Ebla (NW Syria). Rapid Communications in Mass Spectrometry 26: 327-335.

Fiorentino, G., Ferrio, J.P., Bogaard, A., Araus, J.L. and Riehl, S. 2015. Stable isotopes in archaeobotanical research. Vegetation History and Archaeobotany 24: 215-227.

Fletcher, R.A. 1984. Saint James's catapult: the life and times of Diego Gelmírez of Santiago de Compostela. Oxford: Oxford University Press.

Fletcher, R.A. 1987. Reconquest and crusade in Spain, c.1050-1150. Transactions of the Royal Historical Society 37: 31-47.

Fletcher, R.A. 2006. Moorish Spain. University of California Press: Berkeley.

Flohr, P., Jenkins, E., Williams, H.R., Jamjoum, K., Nuimat, S. and Müldner, G. 2019. What can crop stable isotopes ever do for us? An experimental perspective on using cereal carbon stable isotope values for reconstructing water availability in semi-arid and arid environments. Vegetation History and Archaeobotany 28: 497-512.

Forbes, H. 1998. European agriculture viewed bottom-side upwards: fodder-and forage-provision in a traditional Greek community. Environmental Archaeology 1: 19-34.

Forbes, H. 2013. Off-site scatters and the manuring hypothesis in Greek survey archaeology: an ethnographic approach. Hesperia: The Journal of the American School of Classical Studies at Athens, 82: 551-594.

Forbes, H. 2017. Surplus, storage and status in a rural Greek community. World Archaeology 49: 8-25.

Forbes, H. and Foxhall, L. 1995. Ethnoarchaeology and storage in the ancient Mediterranean: beyond risk and survival, pp.69-86 in J. Wilkins, D. Harvey and M. Dobson (eds.), Food in Antiquity. Exeter: University of Exeter Press.

Forey, A.J. 1987. Notes on irrigation in north-eastern Spain during the 12th and 13th centuries. Anuario de Estudios Medievales 17:119-132.

Forey, A.J. 1988. A thirteenth-century dispute between Templars and Hospitallers in Aragon. Durham University Journal 80: 181-192

Forey, A.J. 1992. The military orders: from the twelfth to the early fourteenth centuries. Basingstoke: Macmillan.

Foxhall, L. 1998. Snapping up the unconsidered trifles: the use of agricultural residues in ancient Greek and Roman farming. Environmental Archaeology 1: 35-40.

Fraser, R.A., Bogaard, A., Heaton, T., Charles, M., Jones, G., Christensen, B.T., Halstead, P., Merbach, I., Poulton, P.R., Sparkes, D. and Styring, A.K. 2011. Manuring and stable nitrogen isotope ratios in cereals and pulses: towards a new archaeobotanical approach to the inference of land use and dietary practices. Journal of Archaeological Science 38: 2790-2804.

Fuller, D.Q. 2006. A millet atlas: some identification guidance. London: University College London, Institute of Archaeology.

Fuller, D.Q. and Harvey, E.L. 2006. The archaeobotany of Indian pulses: identification, processing and evidence for cultivation. Environmental Archaeology 11: 219-246.

Fuller, D.Q. and Pelling, R. 2018. Plant economy: archaeobotanical studies, pp.349-368 in E. Fentress and H. Limane (eds.), Volubilis après Rome: Les fouilles UCL/INSAP, 2000-2005. Leiden/Boston: Brill.

Fuller, D.Q. and Stevens, C.J. 2018. Sorghum domestication and diversification: a current archaeobotanical perspective, pp.427-452 in A.M. Mercuri, C. D'Andrea, R. Fornaciari and A. Höhn (eds.), Plants and People in the African Past. Switzerland: Springer Nature.

Fuller, D.Q., Stevens, C.J. and McClatchie, M. 2014. Routine activities, tertiary refuse and labour organisation: social inferences from everyday archaeobotany, pp.174-217 in M. Madella, C. Lancelotti and M. Savard (eds.), Ancient plants and people: contemporary trends in archaeobotany. Tuscon: University of Arizona Press.

García Gómez, E. 1957. Unas" Ordenanzas del zoco" del siglo IX: Traducción del más antiguo antecedente de los tratados andaluces de" hisba" por un autor andaluz. Al-Andalus 22:253-316.

García Manrique, E. 1960. Las comarcas de Borja y Tarazona y el Somontano del Moncayo. Estudio geográfico. Zaragoza: Institución Fernando el Católico.

García Marsilla, J.V., 2013. Alimentación y salud en la Valencia medieval. Teorías y prácticas. Anuario de Estudios Medievales 43: 115-158.

García Sánchez, E. 1983. La alimentación en la Andalucía islámica. Estudio historic y bromatológico. I Cereales y leguminosas. Andalucía Islámica: Textos y Estudios 2-3: 139-178

García Sánchez, E. 1992. Agriculture in Muslim Spain, pp.987-999 in S.M. Jayyusi (ed.), The Legacy of Muslim Spain. Leiden: Brill.

García Sánchez, E. 1995. Cultivos y espacios agrícolas irrigados en Al-Andalus, pp.17-38 in L. Cara Barrionuevo and A. Malpica Cuello (eds.), Agricultura y regadío en Al-Andalus, síntesis y problemas: actas del coloquio, Almería, 9 y 10 de junio de 1995. Almeria: Coloquio Historia y Medio Físico.

García Sánchez, E. 1996. La alimentación popular urbana en al-Andalus. Arqueologia Medieval 4: 219-235.

García Sánchez, E. 2001. Las plantas textile y tintóreas en al-Andalus, pp.417-451 in M. Marín (ed.), Tejer y vestir: de la antigüedad al Islam. Madrid: CSIC.

García Sánchez, E. 2011 La producción frutícola en al-Andalus: un ejemplo de biodiversidad. Estudio Avanzados 16:51-70.

García, C and Bonilla, O. 2010. Primera campaña de prospecciones arqueológicas en la comarca de Tarazona y el Moncayo: avance preliminary de los resultados de la campaña de 2010. Saldvie 10: 271-283.

García-Contreras Ruiz, G. 2018. Feudalización y cambio ecológico en el sector oriental de la Extremadura castellana: poblamiento y paisaje en los territorios de Atienza, Sigüenza y Molina (siglos XI-XIII), pp.51-76 in in J. Torró and E. Guinot Rodríguez (eds.), Trigo y ovejas. El impacto de las conquistas en los paisajes de al-Andalus (siglos XI-XVI). Valencia: Universitat de València.

Gerrard, C.M. 1999. Opposing identity: Muslims, Christians and the Military Orders in Rural Aragon. Medieval Archaeology 43:143-160.

Gerrard, C.M. 2003a. Paisaje y señorío. La casa conventual de Ambel (Zaragoza): arqueología, arquitectura e historia de las Órdenes Militares del Temple y del Hospital. Zaragoza: Institución Fernando el Católico.

Gerrard, C.M. 2003b. Los graffiti, pp.309-347 in C.M. Gerrard (ed.), Paisaje y señorío: la casa conventual de Ambel (Zaragoza). Arqueología, arquitectura e historia de las órdenes religiosas del Temple y del Hospital. Zaragoza: Institución Fernando el Católico.

Gerrard, C.M. 2011. Contest and co-operation: strategies for medieval and later irrigation along the upper Huecha valley, Aragón, north-east Spain. Water History 3: 2-28.

Gerrard, C.M. and Gutiérrez, A. 1995. Excavaciones en la Casa Conventual de Ambel (1993-1995). Unpublished report.

Gerrard, C.M. and Gutiérrez, A. 2003a. Las órdenes militares en Ambel, pp.37-82 in C.M. Gerrard (ed.), Paisaje y señorío: la casa conventual de Ambel (Zaragoza). Arqueología, arquitectura e historia de las órdenes religiosas del Temple y del Hospital. Zaragoza: Institución Fernando el Católico.

Gerrard, C.M. and Gutiérrez, A. 2003b. La villa y paisaje de Templarios y Hospitalarios, pp.83-132 in C.M. Gerrard (ed.), Paisaje y señorío: la casa conventual de Ambel (Zaragoza). Arqueología, arquitectura e historia de las órdenes religiosas del Temple y del Hospital. Zaragoza: Institución Fernando el Católico.

Gerrard, C.M. and Gutiérrez, A. 2012. Estudio arqueológico del Somontano del Moncayo: avance metodológico. Salduie: Estudios de prehistoria y arqueología 10: 259-270.

Gerrard, C.M. and Gutiérrez, A. 2014. Excavaciones in el palacio abacial de Bulbuente (Zaragoza) en 2013 y 2014. Unpublished report.

Gerrard, C.M. and Gutiérrez, A. 2018a. The Qanat in Spain: archaeology and environment, pp.197-226 in J. Berking (ed.), Water management in ancient civilisations. Berlin: Edition Topoi.

Gerrard, C.M. and Gutiérrez, A. 2018b. Excavación arqueológica en La Mora Encantada, Bulbuente (Zaragoza). Unpublished report.

Gerrard, C.M. and Gutiérrez, A. 2020. El estudio arqueológico del Moncayo: resultados preliminares. Unpublished Report.

Glick, T.F. 1970. Irrigation and society in medieval Valencia. Cambridge: Harvard University Press.

Glick, T.F. 1977. Noria pots in Spain. Technology and Culture 18: 644-650.

Glick, T.F. 1979. Islamic and Christian Spain in the Early Middle Ages. New Jersey: Princeton University Press.

Glick, T.F. 1995. From Muslim fortress to Christian castle: social and cultural change in medieval Spain. Manchester: Manchester University Press.

Glick, T.F. 2004. Sistemes agrícoles islàmics de xarq al-Andalus, pp.45-89 in J.M. Salrach (ed.), Història agrària dels Països Catalans. Edat Mitjana II. Barcelona: Fundació Catalana per a la Recerca.

Glick, T.F. 2005. Islam and Christian Spain in the early Middle Ages. Leiden/Boston: Brill.

Glick, T.F. 2006. Irrigation in medieval Spain: A personal narrative across a generation, pp.162-190 in J. Marcus and C. Stanish (eds.), Agricultural Strategies. Los Angeles: California Institute of Archaeology, University of California.

Glick, T.F. and Kirchner, H. 2000. Hydraulic systems and technologies of Islamic Spain: history and archaeology, pp.267-330 in P. Squatriti (ed.), Working with Water in Medieval Europe: Technology and Resource-Use. Leiden: Brill.

Glick, T.F. and Teixeira, S. 2002. Azaira, alhetma: two medieval arabisms reflecting the allocation of irrigation water. Suhayl 3: 213-219.

Goitein, S.D. 1961. The main industries of the Mediterranean area as reflected in the records of the Cairo Geniza. Journal of the Economic and Social History of the Orient 4:168-197.

Gómez-Alonso, S. and García-Romero, E., 2010. Effect of irrigation and variety on oxygen (δ^{18}O) and carbon (δ^{13}C) stable isotope composition of grapes cultivated in a warm climate. Australian Journal of Grape and Wine Research 16: 283-289.

González Palencia, A. 1945. Notas sobre el régimen de riegos en la región de Veruela en los siglos XII y XIII. al-Andalus 10:79-88.

Granja, F. 1967. La marca superior en la obra de Al-Udrí. Zaragoza: Escuela de Estudios Medievales.

Green, F.J. 1979. Phosphatic mineralization of seeds from archaeological sites. Journal of Archaeological Science 6: 279-284.

Greig, J. 1996. Archaeobotanical and historical records compared: a new look at the taphonomy of edible and other useful plants from the 11th to the 18th centuries. Circaea 12: 211-247.

Grew, R. 1999. Food and Global History, pp.1-29 in R. Grew (ed.), Food in Global History. Oxford: Westview Press.

Grigg, D.B. 1974. The agricultural systems of the world: an evolutionary approach. Cambridge: Cambridge University Press.

Gron, K.J., Gröcke, D.R., Larsson, M., Sørensen, L., Larsson, L., Rowley-Conwy, P. and Church, M.J. 2017. Nitrogen isotope evidence for manuring of early Neolithic Funnel Beaker Culture cereals from Stensborg, Sweden. Journal of Archaeological Science: Report 14: 575-579.

Gual, M. 1976 Vocabulario del comercio medieval. Barcelona: El Albir

Guarino, C. and Sciarrillo, R. 2004. Carbonized seeds in a protohistoric house: results of hearth and house experiments. Vegetation History and Archaeobotany 13: 65-70.

Guichard, P. 1976. Al-Andalus: estructura antropológica de una sociedad islámica en Occidente. Barcelona: Barral Editores.

Guichard, P. 1999. Littérature jurisprudentielle et histoire de l'Espagne musulmane: la lente intégration des fatwâ/s malikites à l'historiographie d'al-Andalus. Comptes rendus des séances de l'Académie des Inscriptions et Belles-Lettres 143: 757-779.

Guichard, P. 2000. Quelques remarques sur l'agriculture irriguée dans le centre du Pays Valencien, pp.75-81 in A. Furió and A. Lairón (eds.), L'Espai de l'aigua. Xarxes i sistemes d'irrigació a la Ribera del Xúquer. Valencia: Universitat de València.

Guichard, P. 2001. Al-Andalus frente a la conquista cristiana : los musulmanes de Valencia, siglos XI-XIII. València: Universitat de València.

Guichard, P. and Lagardère V. 1990. La vie sociale et économique de l'Espagne musulmane aux XI-XII siécles á travers les Fatwa/s du Mi'yar d'AI-Wansarisi. Mélanges de la Casa de Velázquez 26: 197-236.

Guillerm, J.L. and Maillet, J. 1982. Western Mediterranean countries of Europe, pp.227-245 in W. Holzner and M. Numata (eds.), Biology and ecology of weeds. London: Junk.

Guinot Rodríguez, E. 2019. Irrigation and political power in the medieval Kingdom of Valencia, pp. M.T. Abata (ed.), Convivencia and Medieval Spain: Essays in Honour of Thomas F. Glick. Cham: Springer International Publishing.

Gutiérrez Lloret, S. 1991. Panes, hogazas y fogones portátiles. Dos formas cerámicas destinadas a la cocción del pan en Al-Andalus: el hornillo (Tannur) y el plato (Tabag). Lucentum 9-10: 161-175.

Gutiérrez Lloret, S. 2015. Early al-Andalus: an archaeological approach to the process of Islamization in the Iberian Peninsula (7th-10th centuries), pp.43-86 in S. Gelichi and R. Hodges (eds.), New Directions in Early Medieval European Archaeology: Spain and Italy Compared. Turnhout: Brepols.

Gutiérrez Lloret, S. 2019. The case of Tudmīr: archaeological evidence for the introduction of irrigation systems in al-Andalus. Early Medieval Europe 27: 394-415.

Gutiérrez, A. 2005. Un viaje a las fortificaciones medievales de Tarazona y el Moncayo. Zaragoza: Diputación Provincial de Zaragoza.

Gutiérrez, A. and Gerrard, C.M. 1992. Excavación en el patio suroeste del Castillo de Grisel (Zaragoza). Turiaso 10, 81-125.

Gutiérrez, A. and Gerrard, C.M. 2019. Excavación arqueológica en Los Pozos, Bureta (Zaragoza). Unpublished report.

Hakbijl, T. 2002. The traditional, historical and prehistoric use of ashes as an insecticide, with an experimental study on the insecticidal efficacy of washed ash. Environmental Archaeology 7: 13-22.

Hallavant, C. and Ruas, M.P. 2014. The first archaeobotanical evidence of Spinacia oleracea L.(spinach) in late 12th–mid 13th century AD France. Vegetation History and Archaeobotany 23: 153-165.

Halliday, G, and Beadle, M. 1982. Consolidated Index to Flora Europaea. Cambridge: Cambridge University Press.

Halstead, P. 1987. Traditional and ancient rural economy in Mediterranean Europe: plus ça change?. The Journal of Hellenic Studies 107: 77-87.

Halstead, P. 1989. The economy has a normal surplus: economic stability and social change among early farming communities of Thessaly, Greece, pp.68-80 in P. Halstead and J. O'Shea (eds.), Bad Year Economics: Cultural Responses to Risk and Uncertainty. Cambridge: Cambridge University Press.

Halstead, P. 1995. Plough and power: the economic and social significance of cultivation with the ox-drawn ard in the Mediterranean. Bulletin on Sumerian Agriculture 8: 11-22.

Halstead, P. 1998. Ask the fellows who lop the hay: leaf-fodder in the mountains of northwest Greece. Rural History 9: 211-234.

Halstead, P. 2014. Two oxen ahead: pre-mechanized farming in the Mediterranean. Cambridge: Wiley: Blackwell.

Halstead, P. and Jones, G. 1989. Agrarian ecology in the Greek Islands: time stress, scale and risk. The Journal of Hellenic Studies 109: 41-55.

Halstead, P., Tierney, J., Butler, S. and Mulder, Y. 1998. Leafy hay: an ethnoarchaeological study in NW Greece. Environmental Archaeology 1: 71-80.

Hare, V.J., Loftus, E., Jeffrey, A. and Ramsey, C.B. 2018. Atmospheric CO_2 effect on stable carbon isotope composition of terrestrial fossil archives. Nature communications 9: 252.

Harlan, J.R. 1978. On the origin of barley, pp.10-36 in A.D. Dickson, J.R. Harlan and D.L. Klingman (eds.), Barley: origin, botany, culture, winter hardiness, genetics, utilisation, pests. Washington: United States Department of Agriculture.

Hartman, G. and Danin, A. 2010. Isotopic values of plants in relation to water availability in the Eastern Mediterranean region. Oecologia 162: 837-852.

Heaton, T.H. 1999. Spatial, species, and temporal variations in the $^{13}C/^{12}C$ ratios of C_3 plants: implications for palaeodiet studies. Journal of Archaeological Science 26: 637-649.

Heaton, T.H., Jones, G., Halstead, P. and Tsipropoulos, T., 2009. Variations in the $^{13}C/^{12}C$ ratios of modern wheat grain, and implications for interpreting data from Bronze Age Assiros Toumba, Greece. Journal of Archaeological Science 36: 2224-2233.

Hedges, R.E.M., Housely, R.A., Bronk Ramsey, C., van Klinken, G.J. 1993. Radiocarbon dates from the Oxford AMS system: Archaeometry datelist 16. Archaeometry 35: 147-167.

Helbaek, H. 1960. Ecological effects of irrigation in ancient Mesopotamia. Iraq 22:186-196.

Henn, T., Jacomet, S., Nagy, D.U. and Pál, R.W. 2015. Desiccated diaspores from building materials: methodological aspects of processing mudbrick for archaeobotanical studies and first results of a study of earth buildings in southwest Hungary. Vegetation History and Archaeobotany 24: 427-440.

Hernández Bermejo, J.E. 1987. Especies botánicas originarias en los jardines de Madinat al-Zahra. Cuadernos de Madinat al-Zahra 1: 61-80.

Hernández Bermejo, J.E. and García Sánchez, E. 1998. Economic botany and ethnobotany in Al-Andalus (Iberian Peninsula: Tenth-Fifteenth Centuries): an unknown heritage of mankind. Economic Botany 52: 15-26.

Hernández Bermejo, J.E., García Sánchez, E. and Carabaza Bravo, J.M. 2012. Flora agrícola y forestal de Al-Andalus. Vol.1. Madrid: Ministerio de Agricultura, Alimentación y Medio Ambiente.

Hernández Charro, M.C. 2006. Agua y poblamiento: Notas sobre la configuración del territorio de Tudela andalusí. Studia historica, Historia medieval 24: 315-339.

Hernández Charro, M.C. 2007. Las transformaciones de la medina de Tudela y su impacto en el paisaje rural andalusí a raíz de la conquista Cristiana, pp.381-394 in B. Arizaga Bolumburu and J.A.

Solórzano Telechea (eds.), La ciudad medieval y su influencia territorial. Logroño: Instituto de Estudios Riojanos.

Hernández Vera, J.A. 2004. La mezquita aljama de Zaragoza a la luz de la información arqueológica. Revista de Ciencias de las Religiones Anejos 10: 65-91.

Hillman, G.C. 1973. Agricultural resources and settlement in the Aşvan region. Anatolian Studies 23: 217-224.

Hillman, G.C. 1978. On the origins of domestic rye—*Secale cereale*: the finds from aceramic Can Hasan III in Turkey. Anatolian Studies 28: 157-174.

Hillman, G.C. 1981. Reconstructing crop husbandry practices from charred remains of crops, pp.123-161 in R. Mercer (ed.), Farming practice in British prehistory. Edinburgh: University of Edinburgh Press.

Hillman, G.C. 1984. Interpretation of archaeological plant remains: The application of ethnographic models from Turkey, pp.1-41 in W. van Zeist and W. A. Casparie (eds.), Plants and ancient man: studies in paleoethnobotany. Rotterdam: A.A. Balkema.

Hillman, G.C. 1985. Traditional husbandry and processing of archaic cereals in modern times. Part II, the free-threshing cereals. Bulletin on Sumerian Agriculture 2: 1-31.

Hillman, G.C. 1991. Phytosociology and ancient weed floras: taking account of taphonomy and changes in cultivation methods, pp.27-40 in D.R. Harris and K.D. Thomas (ed.) Modelling ecological change. London: Institute of Archaeology (UCL).

Hillman, G.C. 2001. Archaeology, Percival and the problems of identifying wheat remains, pp.27-36 in P.D.S. Caligari and P.E. Brandham (eds.), Wheat taxonomy: the legacy of John Percival. London: The Linnean Society, Academic Press.

Hillman, G.C., Mason, S., de Moulins, D. and Nesbitt, M. 1996. Identification of archaeological remains of wheat: the 1992 London workshop. Circaea 12: 195-209.

Hopf, M. 1991. South and southwest Europe, pp.241-277 in W. van Zeist (ed.), Progress in old world palaeoethnobotany. Rotterdam: A.A. Balkema.

Hoppé, C. 1999. A thousand years of farming: agricultural practices from the Byzantine to Early Ottoman period at Khirbet Faris, the Kerak Plateau, Jordan. Unpublished PhD thesis, Department of Archaeology and Prehistory, University of Sheffield.

Horden, P. and Purcell, N. 2000. The corrupting sea: a study of Mediterranean history. Oxford: Blackwell Publishers Ltd.

Houston, J.M. 1964. The western Mediterranean world an introduction to its regional landscapes. London: Longmans.

Hubbard, R.N. and al Azm, A. 1990. Quantifying preservation and distortion in carbonized seeds; and investigating the history of friké production. Journal of Archaeological Science 17: 103-106.

Iberian Climate Atlas 2010. Iberian Climate Atlas. Air Temperature and Precipitation (1971-2000). Madrid: Agencia Estatal de Meteorología.

Imamuddin, S.M. 1965. Some Aspects of the Socio-Economic and Cultural History of Muslim Spain. 711-1492 AD. Leiden: Brill.

Insoll, T. 1999. The archaeology of Islam. Oxford: Blackwell.

Instituto Pirenaico de Ecología y Gobierno de Aragón 2005. Atlas de la flora de Aragón. http://floragon.ipe.csic.es/index.php

Jacomet, S. 2006. Identification of cereal remains from archaeological sites (2nd edition). Basel: Universität Basel, IPAS.

Jiang, Q., Roche, D. and Hole, D.J. 2006. Carbon isotope discrimination of two-rowed and six-rowed barley genotypes under irrigated and non-irrigated field conditions. Canadian Journal of Plant Science 86: 433-441.

Jiménez Castillo, P. and Simón García, J.L. 2018. El poblamiento andalusí en las tierras de secano: el área sudoriental de La Mancha (ss. XI-XIII). Al-Qantara 38:215-259.

Jiménez Puertas, M. 2007. Los regadíos tradicionales del territorio de Loja: historia de unos paisajes agrarios de origen medieval. Loja: Fundación Ibn al-Jatib de Estudios de Cooperación Cultura.

Johns, J. 1984. A Green Revolution? Journal of African History 25:343-368.

Johnson, A.W. 1972. Individuality and experimentation in traditional agriculture. Human Ecology 1: 149-159.

Jones, G. 1984. Interpretation of archaeological plant remains: ethnographic models from Greece, pp.43-61 in In W. van Zeist and W.A. Casparie (eds.) Plants and Ancient Man. Rotterdam: Balkema.

Jones, G. 1987. A statistical approach to the archaeological identification of crop processing. Journal of Archaeological Science 14: 311-323.

Jones, G. 1990. The application of present-day cereal processing studies to charred archaeobotanical remains. Circaea 6: 91–96.

Jones, G. 1991. Numerical analysis in archaeobotany, pp.63-80 in W. van Zeist, K. Wasylikowa and K. Behre (eds.), Progress in old world palaeoethnobotany. Rotterdam: Balkema.

Jones, G. 1992. Weed phytosociology and crop husbandry: identifying a contrast between ancient and modern practice. Review of Palaeobotany and Palynology 73:133-143.

Jones, G. 1996. An ethnoarchaeological investigation of the effects of cereal grain sieving. Circaea 12: 177-182.

Jones, G. 1998. Distinguishing food from fodder in the archaeobotanical record. Environmental Archaeology 1: 95-98.

Jones, G. 2002. Weed ecology as a method for the archaeobotanical recognition of crop husbandry practices. Acta Palaeobotanica 42: 185-193.

Jones, G. and Halstead, P. 1995. Maslins, mixtures and monocrops: On the interpretation of archaeobotanical crop samples of heterogeneous composition. Journal of Archaeological Science 22: 103-114.

Jones, G., Bogaard, A., Charles, M. and Hodgson, J.G. 2000. Distinguishing the effects of agricultural practices relating to fertility and disturbance: a functional ecological approach in archaeobotany. Journal of Archaeological Science 27: 1073-1084.

Jones, G., Bogaard, A., Halstead, P., Charles, M. and Smith, H. 1999. Identifying the intensity of crop husbandry practices on the basis of weed floras. Annual of the British School at Athens 94: 167-189.

Jones, G., Charles, M., Bogaard, A. and Hodgson, J. 2010. Crops and weeds: the role of weed functional ecology in the identification of crop husbandry methods. Journal of Archaeological Science 37: 70-77.

Jones, G., Charles, M., Bogaard, A., Hodgson, J.G. and Palmer, C. 2005. The functional ecology of present-day arable weed floras and its applicability for the identification of past crop husbandry. Vegetation History and Archaeobotany 14: 493-504.

Jones, G., Charles, M., Colledge, S. and Halstead, P. 1995. Towards the archaeobotanical recognition of winter-cereal irrigation: an investigation of modern weed ecology in northern Spain, pp.49-68 in H. Kroll and R. Pasternak (eds.), Res Archaeobotanicae: International Workgroup for Palaeoethnobotany, Proceedings of the 9th symposium. Kiel: Oetker-Vogels.

Jones, M.K. 1991. Sampling in palaeoethnobotany, pp.53-62 in W. van Zeist, K. Wasylikowa and K.E. Behre (eds.), Progress in old world palaeoethnobotany. Rotterdam: A.A. Balkema.

Karg, S. 1995. Plant diversity in late medieval cornfields of northern Switzerland. Vegetation History and Archaeobotany 4: 41-50.

Kennedy, H. 1981. The Early Abbasid Caliphate: a political history. London: Croom Helm.

Kennedy, H. 1996. Muslim Spain and Portugal: a political history of al-Andalus. London: Longman.

Kennedy, H. 2002. An historical atlas of Islam. Leiden: Brill.

Kennedy, H. 2018. From Polis to Madina revisited: some reflections thirty years on, pp.13-20 in S. Panzram and L. Callegarin (eds.), Entre civitas y madīna: el mundo de las ciudades en la Península Ibérica y en el Norte de África (siglos IV-IX). Madrid: Casa de Velázquez.

Kenward, H. and Hall, A. 1997. Enhancing bioarchaeological interpretation using indicator groups: stable manure as a paradigm. Journal of Archaeological Science 24: 663-673.

Khan, H.R., Link, W., Hocking, T.J. and Stoddard, F.L. 2007. Evaluation of physiological traits for improving drought tolerance in faba bean (*Vicia faba* L.). Plant and Soil 29: 205-217.

Khazaei, H., Monneveux, P., Hongbo, S. and Mohammady, S. 2010. Variation for stomatal characteristics and water use efficiency among diploid, tetraploid and hexaploid Iranian wheat landraces. Genetic Resources and Crop Evolution 57: 307-314.

Kirchner, H. 2009. Original design, tribal management and modifications in medieval hydraulic systems in the Baleriac Islands (Spain). World Archaeology 41: 151-168.

Kirchner, H. 2011. Archaeology of the landscape and archaeology of farmed areas in the medieval Hispanic societies. Imago Temporis, Medium Aevum 5: 55-86.

Kirchner, H. 2012. Hidráulica campesina anterior a la generalización del dominio feudal. Casos en Cataluña, pp.21-50 in J. Torró and E. Guinot Rodríguez (eds.), Hidráulica agraria y sociedad feudal: prácticas, técnicas, espacios. Valencia: Universitat de València.

Kirchner, H. 2018. Feudal conquest and colonisation: an archaeological insight into the transformation of Andalusi irrigated spaces in the Balearic Islands, pp.191-227 in T.F. Glick, A.

Malpica, F. Retamero and J. Torró (eds.), From Al-Andalus to the Americas (13th-17th centuries): destruction and construction of societies. Leiden: Brill.

Kirchner, H. 2019. Water management and irrigation in medieval Mediterranean societies: an overview, pp.65-98 in M.T. Abata (ed.), Convivencia and Medieval Spain: Essays in Honour of Thomas F. Glick. Cham: Springer International Publishing.

Kirchner, H. and Retamero, F. 2015. Becoming islanders. Migration and settlement in the Balearic Islands (10th - 13th centuries), pp.57-78 in F. Retamero, I. Schjellerup and A. Davies (eds.) Agricultural and Pastoral Landscapes in Pre-Industrial Society: Choices, Stability and Change. Oxford: Oxbow.

Kirchner, H. and Virgili, A. 2019. Espacios de cultivo vinculados a Madînat Ṭurṭûša (Tortosa, Cataluña): norias, drenajes y campesinos (siglos VIII-XII). Revista de Historia 20:83-112.

Kirchner, H., Virgili, A. and Antolín, F. 2014. Un espacio de cultivo urbano en al-Andalus: Madîna Turṭûša (Tortosa) antes de 1148. Historia Agraria 62: 11-45.

Kislev, M.E., Simchoni, O., Melamed, Y. and Maroz, L. 2011. Flax seed production: evidence from the early Iron Age site of Tel Beth-Shean, Israel and from written sources. Vegetation History and Archaeobotany 20: 579-584.

Kohn, M.J. 2010. Carbon isotope compositions of terrestrial C3 plants as indicators of (paleo) ecology and (paleo) climate. Proceedings of the National Academy of Sciences 107: 19691-19695.

Kohn, M.J. 2016. Carbon isotope discrimination in C3 land plants is independent of natural variations in pCO$_2$. Geochemical Perspectives Letters 2: 35-43.

Körner, C., Farquhar, G.D. and Roksandic, Z. 1988. A global survey of carbon isotope discrimination in plants from high altitude. Oecologia, 74: 623-632.

Körner, C., Farquhar, G.D. and Wong, S.C. 1991. Carbon isotope discrimination by plants follows latitudinal and altitudinal trends. Oecologia 88: 30-40.

Kottmann, L., Schittenhelm, S. and Giesemann, A. 2014. Suitability of carbon isotope discrimination, ash content and single mineral concentration for the selection of drought-tolerant winter rye. Plant Breeding 133: 579-587.

Kress, J.J. 1968. Die islamische Kulturepoche auf der iberischen Halbinsel: eine historisch-Kulturgeographische Studie. Marburg: Geographisches Institut der Universität Marburg.

Kreuz, A. and Marinova, E. 2017. Archaeobotanical evidence of crop growing and diet within the areas of the Karanovo and the Linear Pottery Cultures: a quantitative and qualitative approach. Vegetation History and Archaeobotany 26: 639-657.

Kulikowski, M. 2011. Late Roman Spain and its cities. London: Johns Hopkins University Press.

Küster, H. 1991. Phytosociology and archaeobotany, pp.17-26 in D.R. Harris and K.D. Thomas (ed.) Modelling ecological change. London, Institute of Archaeology (UCL).

Lagardère, V. 1990. Mûrier et culture de la soie en Andalus au Moyen Age (Xe-XIVe siècles). Mélanges de la Casa de Velázquez 26: 97-111.

Lagardère, V. 1993. Campagnes et paysans d'al-Andalus (VIII-XV S.). Paris: Editions Maisonneuve et Larose.

Lagardère, V. 1995. Histoire et société en Occident musulman au Moyen Âge. Madrid: Casa de Velázquez

Laliena Corbera, C. 1986. El Císter en el valle medio del Ebro: repoblación y roturaciones en el dominio del monasterio de Rueda. Anuario de Estudios Medievales 16: 93-106.

Laliena Corbera, C. 1989. Morfología señorial y contabilidades rurales de dos señoríos altoaragoneses en el siglo XIII. España Medieval 12: 107-130.

Laliena Corbera, C. 1998. Expansión territorial, ruptura social y desarrollo de la sociedad feudal en el valle del Ebro, 1080-1120 pp.199-227 in C. Laliena Corbera and J.F. Utrilla Utrilla (eds.), De Toledo a Huesca: Sociedades Medievales en transición a finales del siglo XI (1080-1100). Zaragoza: Institución Fernando el Católico.

Laliena Corbera, C. 2005. Frontera y conquista feudal en el valle del Ebro desde una perspectiva local (Tauste, Zaragoza, 1086-1200). Studia Historica, Historia Medieval 23:115-138.

Laliena Corbera, C. 2007. Tierra, poblamiento y renta señorial. Una revisión de problemas generales sobre la organización social del espacio en el valle del Ebro del siglo XII, pp.129-150 in E. Sarasa Sánchez (ed.), Las Cinco Villas aragonesas en la Europa de los siglos XII y XIII: de la frontera natural a las fronteras políticas y socioeconómicas. Zaragoza: Institución Fernando el Católico.

Laliena Corbera, C. 2008. Licencias para la exportación de cereal de Aragón y Cataluña a mediados del siglo XIII. Aragón en la Edad Media 20:445-456.

Laliena Corbera, C. 2010. Arqueología del poblamiento en el Aragón Medieval (siglos X-XIII): problemas de historia social, pp.29-52 in J.M. Ortega Ortega & J.C. Escriche (eds.), Jornadas de arqueología medieval en Aragón: balance y novedades. Teruel: Instituto de Estudios Turolenses

Laliena Corbera, C. and Ortega Ortega, J.M. 2011. Estructuras agrarias y despoblados de los siglos XII y XIII en el Bajo Aragón feudal, pp.145-176 in F. Sabaté and J. Brufal Sucarrat (eds.), Els espais de secà. Lleida: Pagès Editors.

Laliena Corbera, C. and Ortega Ortega, J.M. 2012. Formas feudales de especulación agraria: villas, viñas y acequias en el sur de Aragón (ca. 1170-1240), pp.79-102 in J. Torró and E. Guinot Rodríguez (eds.), Hidráulica agraria y sociedad feudal: prácticas, técnicas, espacios. Valencia: Universitat de València.

Lataowa, M. 1998. Botanical analysis of a bundle of flax (*Linum usitatissimum* L.) from an early medieval site in northern Poland: a contribution to the history of flax cultivation and its field weeds. Vegetation History and Archaeobotany 7: 97-107.

Latorre Ciria, J.M. 2007. La producción agraria en el sur de Aragón (1660-1827). Historia Agraria 41: 3-30.

Lautensach, H. 1960. Maurische Züge im geographischen Bild der iberischen Halbinsel. Bonn: Bonner Geographische Abhandlungen.

Lerín de Pablo, J. 1999. Relaciones económicas y pleitos del monasterio de Veruela con sus convecinos en los siglo XII al XVIII. Cuadernos de Estudios Borjanos 41-42: 43-99.

Lévi-Provençal, E. 1932. L'Espagne musulmane au Xème siècle: institutions et vie sociale. Paris: Larose.

Lévi-Provençal, E. 1953. Histoire de l'Espagne musulmane. Vol.3 Le siècle du califat de Cordoue. Paris: G.P. Maisonneuve.

Lewit, T. 2003. ‘Vanishing villas’: what happened to élite rural habitation in the West in the 5th-6th c?. Journal of Roman Archaeology 16: 260-274.

Lewit, T. 2005. Villas, farms and the late Roman rural economy: (third to fifth centuries AD). Oxford: Archaeopress.

Lightfoot, E. and Stevens, R.E. 2012. Stable isotope investigations of charred barley (*Hordeum vulgare*) and wheat (*Triticum spelta*) grains from Danebury Hillfort: implications for palaeodietary reconstructions. Journal of Archaeological Science 39: 656-662.

Lister, D.L. and Jones, M.K. 2013. Is naked barley an eastern or a western crop? The combined evidence of archaeobotany and genetics. Vegetation History and Archaeobotany 22: 439-446.

Livarda, A. 2008. Introduction and dispersal of exotic food plants into Europe during the Roman and medieval periods. University of Leicester, PhD Thesis.

Livarda, A. and van der Veen, M. 2008. Social access and dispersal of condiments in North-West Europe from the Roman to the medieval period. Vegetation History and Archaeobotany 17: 201-209.

Livarda, A. 2011. Spicing up life in northwestern Europe: exotic food plant imports in the Roman and medieval world. Vegetation History and Archaeobotany 20: 143-164.

Llavero, E. 1990. La medicina andalusí y su aportación a la botánica. Ciencias de la Naturaleza en al-Andalus.Textos y Estudios 1: 93-105.

Lloveras, J., Santiveri, F. and Gorchs, G. 2006. Hemp and flax biomass and fiber production and linseed yield in irrigated Mediterranean conditions. Journal of industrial Hemp 11: 3-15.

Lodwick, L. 2019. Agendas for Archaeobotany in the 21st Century: data, dissemination and new directions. Internet Archaeology 53.

Lodwick, L. and Stroud, E. 2019. Paleoethnobotany and Stable Isotopes, in S.L. López Varela (ed.), The Encyclopedia of Archaeological Sciences. Chichester, West Sussex: Wiley Blackwell.

López Garí, J.M. and Marlasca, R. 2009. L’Edat mitjana. El naixament de Ses Feixes, pp.77-94 in Vila i Ses Feixes. Els camins de l’aigua. Eivissa: GEN-GOB.

López López, A.C. 1994. Estudio particular de las especies botánicas que se citan en el Calendario de Cordóba de ‘Arīb ibn Sa‘d’. Ciencias de la Naturaleza en al-Andalus. Textos y Estudios 3: 43-78.

López-Blanco, C. and Romero-Viana, L. 2019. Dry and wet periods over the last millennium in central-eastern Spain-a paleolimnological perspective. Limnetica, 38: 335-352.

Lorenzo Jiménez, J. 2007. Los husún de los Banu Qasi: algunas consideraciones desde el registro escrito. Brocar: Cuadernos de investigación histórica 31: 79-106.

Lüning, S., Schulte, L., Garcés-Pastor, S., Danladi, I.B. and Gałka, M. 2019. The Medieval Climate Anomaly in the Mediterranean region. Paleoceanography and Paleoclimatology.

Magallón Botoya, M. 2006. El mundo tardoromano en el Valle Medio del Ebro: las ciudades, pp.9-13 in P. Sénac (ed.), De la Tarraconaise à la marche supérieure d'al-Andalus (IV-XI siècle): les habitats ruraux. Toulouse: Université de Toulouse-Le Mirail.

Maier, U. 1996. Morphological studies of free-threshing wheat ears from a Neolithic site in southwest Germany, and the history of the naked wheats. Vegetation History and Archaeobotany 5: 39-55.

Malalana Ureña, A., Morín de Pablos, J., and Barroso Cabrera, R. 2013. Acerca de la funcionalidad de los denominados "silos-basureros": una propuesta metodológica para el estudio de la agricultura andalusí en época califal y taifa. Archaeologia Medievale 150:337-352.

Malouta, M. and Wilson, A. 2012. Mechanical irrigation: water-lifting devices in the archaeological evidence and in the Egyptian papyri, pp.273-306 in A. Bowman and A. Wilson (eds.), The Roman Agricultural Economy: Organisation, Investment, and Production. Oxford: Oxford University Press.

Malpica Cuello, A. 2015. The emergence of the city in al-Andalus, pp.87-111 in S. Gelichi and R. Hodges (eds.), New Directions in Early Medieval European Archaeology: Spain and Italy Compared. Turnhout: Brepols.

Mangafa, M. and Kotsakis, K. 1996. A new method for the identification of wild and cultivated charred grape seeds. Journal of Archaeological Science 23: 409-418.

Mann, M.E. and Jones, P.D. 2003. Global surface temperatures over the past two millennia. Geophysical Research Letters 30: 1820.

Mann, M.E., Zhang, Z., Hughes, M.K., Bradley, R.S., Miller, S.K., Rutherford, S. and Ni, F. 2008. Proxy-based reconstructions of hemispheric and global surface temperature variations over the past two millennia. Proceedings of the National Academy of Sciences 105: 13252-13257.

Mann, M.E., Zhang, Z., Rutherford, S., Bradley, R.S., Hughes, M.K., Shindell, D., Ammann, C., Faluvegi, G. and Ni, F. 2009. Global signatures and dynamical origins of the Little Ice Age and Medieval Climate Anomaly. Science 326: 1256-1260.

Manzano Moreno, E. 1986. La rebelión del año 754 en la Marca Superior y su tratamiento en las crónicas árabes. Studia Historica, Historia Medieval 4:185-203.

Manzano Moreno, E. 1991. La frontera de Al-Andalus en epoca de los omeya. Madrid: CSIC.

Manzano Moreno, E. 1993. Beréberes de al-Andalus: los factores de una evolución histórica. Al-qantara 11: 397-428.

Manzano Moreno, E. 2006. Conquistadores, emires y califas: los omeyas y la formación de Al-Andalus. Barcelona: Crítica.

Manzano Moreno, E. 2012. Al-Andalus: un balance crítico, pp.19-31 in P. Sénac (ed.), Histoire et archéologie de l'Occident musulman (VIIe-XVe siècles): Al-Andalus, Maghreb, Sicile. Toulouse: CNRS-Université de Toulouse-Le Mirail.

Manzano Moreno, E. 2018. Entre faits et artefacts; interprétations historiques et données archéologiques en al-Andalus, pp.93-112 in Bourgeois, L., Alexandre-Bidon, D., Feller, L., Mane, P., Verna, C. and Wilmart, M. (ed.), La culture matérielle: un objet en question. Anthropologie, archéologie et histoire. Caen: Presses Universitaires de Caen.

Margaritis, E. and Jones, M., 2006. Beyond cereals: crop processing and *Vitis vinifera* L. Ethnography, experiment and charred grape remains from Hellenistic Greece. Journal of Archaeological Science 33: 784-805.

Marín, M. 2003. En los márgenes de la ley: el consumo de alcohol en al Andalus, pp.271-328 in C. de la Puente (ed.), Estudios onomástico-biográficos de al Andalus (Identidades marginales) XIII. Madrid: CSIC.

Märkle, T. and Rösch, M. 2008. Experiments on the effects of carbonization on some cultivated plant seeds. Vegetation History and Archaeobotany 17: 257-263.

Marshall, L.R., Almond, M.J., Cook, S.R., Pantos, M., Tobin, M.J. and Thomas, L.A. 2008. Mineralised organic remains from cesspits at the Roman town of Silchester: processes and preservation. Spectrochimica Acta Part A 71: 854-861.

Marston, J. 2012. Agricultural strategies and political economy in ancient Anatolia. American Journal of Archaeology 116: 377-403.

Marston, J.M. and Miller, N.F. 2014. Intensive agriculture and land use at Roman Gordion, central Turkey. Vegetation History and Archaeobotany 23: 761-773.

Martín Civantos, J.M. 2011. Working in landscape archaeology: the social and territorial significance of the agricultural revolution in al-Andalus. Early Medieval Europe 19: 385-410.

Martín Civantos, J.M. 2018. Water management and irrigation systems in the medieval Mediterranean, in F. Sulas and Pikirayi, I. (eds.), Water and Society from Ancient Times to the Present: Resilience, Decline and Revival. Oxford: Routledge.

Martin Duque, A.J. 1956. Aragón y Navarra según el "Kitab ar-Rawd al mi tar". Argensola, 27: 247-258.

Martínez Enamorado, V. 2003. Al-Andalus desde la periferia: la formación de una sociedad musulmana en tierras Malagueñas (siglos VIII-X). Málaga: Servicio de Publicaciones, Centro de Ediciones de la Diputación de Málaga.

Masi, A., Sadori, L., Restelli, F.B., Baneschi, I. and Zanchetta, G. 2014. Stable carbon isotope analysis as a crop management indicator at Arslantepe (Malatya, Turkey) during the Late Chalcolithic and Early Bronze Age. Vegetation History and Archaeobotany 23: 751-760.

Mathews, W. 2010. Geoarchaeology and taphonomy of plant remains and microarchaeological residues in early urban environments in the Ancient Near East. Quaternary International 214: 98-113.

McCobb, L.E., Briggs, D.E.G., Carruthers, W.J. and Evershed, R. 2003. Phosphatisation of seeds and roots in a Late Bronze Age deposit at Potterne, Wiltshire, UK. Journal of Archaeological Science 30: 1269-1281.

McCobb, L.E., Briggs, D.E.G., Evershed, R.P., Hall, A.R. and Hall, R. 2001. Preservation of fossil seeds from a 10th century AD cess pit at Coppergate, York. Journal of Archaeological Science 28: 929-940.

McKerracher, M. 2019. Anglo-Saxon crops and weeds: a case study in quantitative archaeobotany. Oxford: Archeopress.

Merah, O. and Monneveux, P. 2015. Contribution of different organs to grain filling in durum wheat under Mediterranean conditions 1: contribution of post-anthesis photosynthesis and remobilization. Journal of Agronomy and Crop Science 201: 344-352.

Merah, O., Deléens, E. and Monneveux, P. 1999. Grain yield, carbon isotope discrimination, mineral and silicon content in durum wheat under different precipitation regimes. Physiologia Plantarum 107: 387-394.

Merah, O., Deléens, E., Teulat, B. and Monneveux, P., 2002. Association between yield and carbon isotope discrimination value in different organs of durum wheat under drought. Journal of Agronomy and Crop Science 188: 426-434.

Miksicek, C.H. 1987. Formation processes of the archaeobotanical record. Advances in Archaeological Method and Theory 10: 211-247.

Miller, N.F. 1982. Economy and environment of Malyan, a third millennium BC urban centre in southern Iran. Unpublished PhD Thesis, University of Michigan.

Miller, N.F. 1984. The use of dung as fuel: an ethnographic example and an archaeological application. Paléorient 10: 71-79.

Miller, N.F. 2011. Botanical Aspects of Environment and Economy at Gordion, Turkey. Philadelphia: University of Pennsylvania Press.

Miller, N.F. and Smart, T.L. 1984. Intentional burning of dung as fuel: a mechanism for the incorporation of charred seeds into the archaeological record. Journal of Ethnobiology 4: 15-28.

Miller, N.F., Spengler, R.N. and Frachetti, M. 2016. Millet cultivation across Eurasia: Origins, spread, and the influence of seasonal climate. The Holocene 26: 1566-1575.

Molinari, A. 2015. 'Islamisation' and the rural world: Sicily and al-Andalus, pp.187-220 in S. Gelichi and R. Hodges (eds.), New Directions in Early Medieval European Archaeology: Spain and Italy Compared. Turnhout: Brepols.

Monneveux, P., Rekika, D., Acevedo, E. and Merah, O. 2006. Effect of drought on leaf gas exchange, carbon isotope discrimination, transpiration efficiency and productivity in field grown durum wheat genotypes. Plant Science 170: 867-872.

Monneveux, P., Reynolds, M.P., Trethowan, R., González-Santoyo, H., Peña, R.J. and Zapata, F. 2005. Relationship between grain yield and carbon isotope discrimination in bread wheat under four water regimes. European Journal of Agronomy 22: 231-242.

Monneveux, P., Reynolds, M.P., Trethowan, R., Peña, J. and Zapata, F. 2004. Carbon isotope discrimination, leaf ash content and grain yield in bread and durum wheat grown under full-irrigated conditions. Journal of Agronomy and Crop Science 190: 389-394.

Monterde Albiac, C. and Cabanes Pecourt, M.D. 2000. Aragón en las cartas reales de Jaime II (1290-1300). Aragón en la Edad Media 16: 521-554.

Mora-González, A., Delgado-Huertas, A., Granados-Torres, A., Cortés, F.C., Maestre, F.J.J. and Padilla, J.A.L. 2016. The isotopic footprint of irrigation in the western Mediterranean basin during the Bronze Age: the settlement of Terlinques, southeast Iberian Peninsula. Vegetation History and Archaeobotany 25: 459-468.

Mora-González, A., Delgado-Huertas, A., Granados-Torres, A., Cortés, F.C., Soldevila, I.P. and Espino, D.D. 2018. Complex agriculture during the second millennium BC: isotope composition of carbon studies ($\delta^{13}C$) in archaeological plants of the settlement Cerro del Castillo de Alange (SW Iberian Peninsula, Spain). Vegetation History and Archaeobotany 27: 453-462.

Mora-González, A., Fernandes, R., Cortés, F.C., Granados-Torres, A., García, E.A. and Delgado-Huertas, A. 2019a. Reporting atmospheric CO_2 pressure corrected results of stable carbon isotope analyses of cereals remains from the archaeological site of Peñalosa (SE Iberian Peninsula): agricultural and social implications. Archaeological and Anthropological Sciences 11: 1995-2005.

Mora-González, A., Teira-Brión, A., Granados-Torres, A., Contreras-Cortés, F. and Delgado-Huertas, A. 2019b. Agricultural production in the 1st millennium BCE in Northwest Iberia: results of carbon isotope analysis. Archaeological and Anthropological Sciences 11: 2897-2909.

Moragues, M., Moralejo, M., Sorrells, M.E. and Royo, C. 2007. Dispersal of durum wheat [*Triticum turgidum* L. ssp. *turgidum* convar. *durum* (Desf.) MacKey] landraces across the Mediterranean basin assessed by AFLPs and microsatellites. Genetic Resources and Crop Evolution 54: 1133-1144.

Morales, J., Pérez-Jordà, G., Eiroa, J.A. Fátima Palma, M. and Peña-Chocarro, L. 2019. Earliest evidence of citrus fruit in the Iberian Peninsula. Abstract in 18th Conference of the International Workgroup for Palaeoethnobotany (IWGP). Salento: University of Salento.

Moreno García, M. 1997. The zooarchaeological evidence for transhumance in medieval Spain, pp.45-54 in G. de Boe and F. Verhaeghe (eds.), Environment and subsistence in medieval Europe. Zellik: Instituut voor het Archeologisch Patrimonium.

Moreno, A., Morellón, M., Martín-Pueras, C., Frigola, J., Canals, M., Cacho, I. and Corella, J.P. 2011. Was there a common hydrological pattern in the Iberian Peninsula region during the Medieval Climate Anomaly? PAGES 19: 16-18.

Moreno, A., Pérez, A., Frigola, J., Nieto-Moreno, V., Rodrigo-Gámiz, M., Martrat, B., González-Sampériz, P., Morellón, M., Martín-Puertas, C., Corella, J.P. and Belmonte, Á. 2012. The Medieval Climate Anomaly in the Iberian Peninsula reconstructed from marine and lake records. Quaternary Science Reviews 43: 16-32.

Moreno-Larrazabal, A., Teira-Brión, A., Sopelana-Salcedo, I., Arranz-Otaegui, A. and Zapata Peña, L. 2015. Ethnobotany of millet cultivation in the north of the Iberian Peninsula. Vegetation History and Archaeobotany 24: 541-554.

Motis, M.A. 1985. Explotaciones agrarias de los judíos de Tarazona (Zaragoza) a fines del siglo XV. Sefarad 45: 353-390

Motis, M.A. 1988. Régimen de explotación de las propiedades agrarias de los judíos en el Noroeste del reino de Aragón en el siglo XV. Hispania 48: 405-492.

Motuzaite-Matuzeviciute, G., Staff, R.A., Hunt, H.V., Liu, X. and Jones, M.K. 2013. The early chronology of broomcorn millet (*Panicum miliaceum*) in Europe. Antiquity 87: 1073-1085.

Muñoz Garrido, V. 1999. Asentamiento del patrimonio del capítulo general de racioneros de Teruel en la Baja Edad Media. Aragón en la Edad Media 14: 1151-1166.

Navarro Espinach, G. 1999. Teruel en la Edad Media, Balance y perspectivas de investigación. Aragón en la Edad Media 14: 1199-1226.

Navarro Espinach, G. 2003a. La industria textil en los reinos de Aragón y Valencia en la Edad Media, pp.475-492 in S. Claramunt Rodríguez (ed.), El món urbà a la Corona d'Aragó del 1137 als decrets de Nova Planta: XVII Congrés d'Història de la Corona d'Aragó. Barcelona: Universitat de Barcelona.

Navarro Espinach, G., 2003b. El desarrollo industrial de Aragón en la Baja Edad Media. Aragón en la Edad Media 17: 179-212.

Navarro Espinach, G. 2017. De Rubielos a Mirambel: economías locales en los límites del reino, pp.81-118 in E. Sarasa Sánchez (ed.). Bajar al reino: relaciones sociales, económicas y comerciales entre Aragón y Valencia: siglos XIII-XV. Zaragoza: Institución Fernando el Católico.

Navarro Palazón, J. and Jiménez Castillo, P. 2007. Algunas reflexiones sobre el urbanismo islámico. Artigrama 22:259-298.

Navarro Palazón, J. and Robles Fernández, A. 1996. Liétor : formas de vida rurales en Sarq al-Andalus a través de una ocultación de los siglos X-XI Murcia: Centro de Estudios Árabes y Arqueológicos "Ibn Arabi".

Neef, R., Cappers, R.T.J. and Bekker, R.M. 2011. Digital atlas of economic plants in archaeology. Groningen: Barkhuis.

Nesbitt, M. and Summers, G.D. 1988. Some recent discoveries of millet (*Panicum miliaceum* L. and *Setaria italica* (L.) P. Beauv.) at excavations in Turkey and Iran. Anatolian Studies 38: 85-97.

Nesbitt, M., Bates, J., Hillman, G.C. and Mitchell, S. 2017. The archaeobotany of Aşvan: environment & cultivation in Eastern Anatolia from the Chalcolithic to the Medieval period. London: British Institute at Ankara.

Netting, R.M. 1993. Smallholders, householders: farm families and the ecology of intensive, sustainable agriculture. Stanford: Stanford University Press.

Nitsch, E., Andreou, S., Creuzieux, A., Gardeisen, A., Halstead, P., Isaakidou, V., Karathanou, A., Kotsachristou, D., Nikolaidou, D., Papanthimou, A. and Petridou, C. 2017. A bottom-up view of food surplus: using stable carbon and nitrogen isotope analysis to investigate agricultural strategies and diet at Bronze Age Archontiko and Thessaloniki Toumba, northern Greece. World Archaeology 49: 105-137.

Nitsch, E.K., Charles, M. and Bogaard, A. 2015. Calculating a statistically robust $\delta^{13}C$ and $\delta^{15}N$ offset for charred cereal and pulse seeds. STAR 1

Nitsch, E.K., Jones, G., Sarpaki, A., Hald, M.M., and Bogaard, A. 2019a. Farming practice and land management at Knossos, Crete: new insights from $\delta^{13}C$ and $\delta^{15}N$ analysis of Neolithic and Bronze Age crop remains, pp. 159-174 in D. Garcia, R. Orgeolet, M. Pomadère and J. Zurbach (eds.), The country in the city: agricultural functions of protohistoric urban settlements (Aegean and Western Mediterranean). Oxford: Archeopres.

Nitsch, E.K., Lamb, A.L., Heaton, T.H.E., Vaiglova, P., Fraser, R., Hartman, G., Moreno-Jiménez, E., López-Piñeiro, A., Peña-Abades, D., Fairbairn, A. and Eriksen, J. 2019b. The preservation and interpretation of $\delta^{34}S$ values in charred archaeobotanical remains. Archaeometry 61: 161-178.

Núñez, D.R., de Castro, C. O., and Asencio Martínez, A. 1988. Arqueobotánica y Paleoetnobotánica en el Sureste de España, datos preliminares. Trabajos de Prehistoria 45: 317-334.

O'Connell, T.C., Ballantyne, R.M., Hamilton-Dyer, S., Margaritis, E., Pantano, W., Millett, M. and Keay, S.J. 2019. Living and dying at the Portus Romae. Antiquity 93: 719-734.

Olalde, I. et al. 2019. The genomic history of the Iberian Peninsula over the past 8000 years. Science 363: 1230-1234.

O'Leary, M.H. 1981. Carbon isotope fractionation in plants. Phytochemistry 20: 553-567.

O'Leary, M.H. 1988. Carbon isotopes in photosynthesis. Bioscience 38: 328-336.

Oliva, M., Ruiz-Fernández, J., Barriendos, M., Benito, G., Cuadrat, J.M., García-Ruiz, J.M., Giralt, S., Gómez-Ortiz, A., Hernández, A., López-Costas, O., López-Moreno, J.I.,López-Sáez, J.A., Martínez-Cortizas, A., Moreno, A., Prohom, M., Saz, M.A., Serrano, E., Tejedor, E., Trigo, R., Valero-Garcés, B., Vicente-Serrano, S., 2018. The Little Ice Age in Iberian mountains. Earth Science Reviews 177: 175–208.

Oliveira, H.R., Campana, M.G., Jones, H., Hunt, H.V., Leigh, F., Redhouse, D.I., Lister, D.L. and Jones, M.K. 2012. Tetraploid wheat landraces in the Mediterranean basin: taxonomy, evolution and genetic diversity. Plos one, 7.e37063.

Olmo Enciso, L. 2011. De Celtiberia a Šantabariyya: la gestación del espacio y el proceso de formación de la sociedad andalusí (ss. VIII-IX), pp.39-62 in E. Baquedano (ed.), 711: Arqueología e Historia entre dos Mundos. Madrid: Museo Arqueológico Regional.

Olmo Enciso, L. 2015.The materiality of complex landscapes: central Iberia during 6th-8th centuries AD, pp.15-42 in S. Gelichi and R. Hodges (eds.), New Directions in Early Medieval European Archaeology: Spain and Italy Compared. Turnhout: Brepols.

Orendi, A. in press. Flax cultivation in the southern Levant and its development during the Bronze and Iron Age. Quaternary International.

Ortega Ortega, J.M. 1998. Sociedad y administración del territorio en el tagr al-ʻalà: El ejemplo del iqlim de Qutanda. Arqueología y Territorio Medieval 5: 31-54.

Ortega Ortega, J. 2004. Castillos y recintos amurallados en las serranías de Gúdar y Javalambre, pp.85-92 in M.V. Lozano Tena (ed.), Comarca de Gúdar-Javalambre. Zaragoza: Diputación General de Aragón.

Ortega Ortega, J.M. 2008. Consideraciones sobre la explotación del hierro en la Sierra Menera (Teruel) durante época andalusí, pp.95-122 in A. Canto and P. Cressier (eds.), Minas y metalurgia en al-Andalus y en el Magreb occidental: explotación y poblamiento. Madrid: Casa de Velázquez.

Ortega Ortega, J. 2010. La agricultura de los vencedores y la agricultura de los vencidos: La investigación de las transformaciones feudales de los paisajes agrarios en el valle del Ebro (siglos XII-XIII), pp.123-146 in H. Kirchner (ed.), Por una arqueología agraria: perspecivas de investigación sobre espacios de cultivo en las Sociedad Oxford: Archeopress (British Archaeological Reports International Series 2062).

Ortega Ortega, J. 2018. La conquista Islámica de la península Ibérica: una perspectiva arqueológica. Madrid: La Ergástula.

Oweis, T., Hachum, A. and Pala, M. 2004. Lentil production under supplemental irrigation in a Mediterranean environment. Agricultural Water Management 68: 251-265.

Ouerfelli, M. 2008. Le sucre: production, commercialisation et usages dans la Méditerranée médiévale. Boston: Brill.

Paris, H.S. 2015. Origin and emergence of the sweet dessert watermelon, *Citrullus lanatus*. Annals of Botany 116: 133-148.

Parra Villaescusa, M. 2013. Explotación agrícola en el sur del Reino de Valencia. El cultivo del arroz en Orihuela a finales de la Edad Media. Medievalismo 23: 11-41.

Paz, J, 2004. Contribución a la historia numismática de época visigoda e hispanovisigoda: el context historic-arqueológico de los hallazgos en Aragón. Bolskan 21: 11-25.

Pellat, C. 1960. Le Calendrier de Cordoue publié par R. Dozy. Nouvelle edition accompagnée d'une traduction Française annotée. Leiden: Brill.

Pelling, R. 2008. Garamantian agriculture: the plant remains from Jarma, Fazzan. Libyan Studies 39: 41-71.

Peña-Chocarro, L. 1999. Prehistoric agriculture in southern Spain during the Neolithic and the Bronze Age: the application of ethnographic models. Oxford: Archeopress (British Archaeological Reports International Series 818).

Peña-Chocarro, L. and Pérez Jordà, G., 2019. Garden plants in medieval Iberia: the archaeobotanical evidence. Early Medieval Europe 27: 374-393.

Peña-Chocarro, L. and Pérez-Jordà, G. 2018. Los estudios carpológicos en la Península Ibérica: un estado de la cuestión. Pyrenae, 49: 7-45.

Peña-Chocarro, L. and Zapata Peña, L. 1999. History and traditional cultivation of *Lathyrus sativus* L. and *Lathyrus citera* L. in the Iberian Peninsula. Vegetation History and Archaeobotany 8: 49-52.

Peña-Chocarro, L., Alkain, P. and Urteaga, M. 2014. Wild, managed and cultivated plants in Northern Iberia: an archaeobotanical approach to medieval plant exploitation in the País Vasco. European Journal of Post-Classical Archaeologies 4: 131-156.

Peña-Chocarro, L., Pérez Jordà, G. Morales Mateos, J. and Zapata Peña, L. 2015. Storage in traditional farming communities of the western Mediterranean: Ethnographic, historical and archaeological data. Environmental Archaeology, 20: 379-389.

Peña-Chocarro, L., Pérez Jordà, G., Alonso, N., Antolín, F., Teira Brión, A., Tereso, J.P., Moya, E.M.M. and Reyes, D.L. 2019. Roman and medieval crops in the Iberian Peninsula: A first overview of seeds and fruits from archaeological sites. Quaternary International 499: 49-66.

Peñuelas, J., Isla, R., Filella, I. and Araus, J.L. 1997. Visible and near-infrared reflectance assessment of salinity effects on barley. Crop science 37: 198-202.

Pérez Giménez, M.R. 2003. Agua y pastos; luchas y alianzas por el control del valle de la Huecha entre la ciudad de Borja y el Monasterio de Santa María de Veruela pp.737-754 in S. Claramunt Rodríguez (ed.), El món urbà a la Corona d'Aragó del 1137 als decrets de nova planta. Barcelona: Publicacions Universitat de Barcelona.

Pérez-Jordà, G., Peña-Chocarro, L., Fernández, M.G. and Rodríguez, J.C.V. 2017. The beginnings of fruit tree cultivation in the Iberian Peninsula: plant remains from the city of Huelva (southern Spain). Vegetation History and Archaeobotany 26: 527-538.

Pico Torné, M. 2015. De la alquería de Benifassà a las granjas cistercienses de Ballestar y Cel Albar (1195-1279). (La Pobla de Benifassà, Castellón, España), pp.132-154 in C. Sanchis Ibor, G Palau Salvador, I. Mangue Alférez and L.P. Martínez-Sanmartín (eds.), Irrigation, Society and Landscape. Tribute to Tom F. Glick. València: Editorial Universitat Politècnica de València Hispana.

Pietro Brogiolo, G. and Chavarría i Arnau, A. 2008. El final de las villas y las transformaciones del territorio rural en Occidente (siglos V-VIII), pp.193-214 in C. Fernández Ochoa, V. García Entero and F. Gil Sendin (eds.), Las "villae" tardorromanas en el Occidente del Imperio. Gijón: Trea.

Pinilla, V. 2006. The development of irrigated agriculture in twentieth-century Spain: a case study of the Ebro basin. Agricultural History Review 54: 122-141.

Pinto Da Silva, A. R. 1988. A paleobotánica na arqueología portuguesa. Resultados desde 1931 a 1987. pp.5–49 in F. Queiroga, I. Sousa and C. Oliveira (eds), Actas do Encontro Palaeocologia e Arqueologia. Câmara Municipal: Vila Nova de Famalicâo.

Pluscowksi, A., Boas, A.J. and Gerrard, C. 2011. The ecology of crusading: Investigating the environmental impact of holy war and colonisation at the frontiers of medieval Europe. Medieval Archaeology 55: 192-225.

Ponsot, P. 1971. Les Morisques, la culture irriguée du blé et le problème de la décadence de l'agriculture espagnole au XVIIe siècle. Un témoignage sur la Vega de Tarazona. Mélanges de la Casa de Velázquez 7: 237-262.

Pradat, B. and Ruas, M.P. 2017. Plante importée ou acclimatée: le sorgho (Sorghum bicolor (L.) Moench) dans le nord de l'Aquitaine au Moyen Âge 177-190 in N. Rovira, L. Bouby, A. Bouchette and M.P. Ruas (eds.) Plantes, Produits et pratiques: diffusion et adoption de la nouveauté dans les sociétés préindustrielles, Actes des Rencontres d'Archéobotanique 2010, 13-16 Octobre 2010. Lattes: ADALR.

Prentice, I.C., Meng, T., Wang, H., Harrison, S.P., Ni, J. and Wang, G. 2011. Evidence of a universal scaling relationship for leaf CO_2 drawdown along an aridity gradient. New Phytologist 190: 169-180.

Prevedorou, E., Díaz-Zorita Bonilla, M., Romero, A., Buikstra, J.E., Paz de Miguel Ibáñez, M. and Knudson, K.J. 2010. Residential mobility and dental decoration in Early Medieval Spain: results from the eighth century site of Plaza del Castillo, Pamplona. Dental Anthropology 23: 42-52.

Puig, C. 2005. La place des fruits en Méditerranée nord-occidentale à partir des actes de la pratique et des tarifs marchands (XIIe-Première moitié XIVe siècles). Archéologie du Midi Médiéval 23: 119-128.

Puy, A., Balbo, A.L., Virgili, A. and Kirchner, H. 2014. The evolution of Mediterranean wetlands in the first millennium AD: The case of Les Arenes floodplain (Tortosa, NE Spain). Geoderma 232: 219-235.

Queiroz, P.F. 2009. Estudo Arqueobotânico, pp.151-183 in L. Batalha, J.C. Caninas, G. Cardoso and M. Monteiro, A villa romana da subserra de Castanheira do Ribatejo (Vila Franca de Xira). Trabalhos arqueológicos de uma obra da EPAL, S.A. Lisbon: EPAL.

Ramón-Laca, L. and Mabberley, D.J. 2004. The ecological status of the carob-tree (*Ceratonia siliqua*, Leguminosae) in the Mediterranean. Botanical Journal of the Linnean Society 144: 431-436.

Reihl, S. and Nesbitt, M. 2003. Crops and cultivation in the Iron Age Near East: change or continuity?, pp.301-312 in B. Fischer, H. Genz, E. Jean and K. Köroğlu (eds.), Identifying changes: the transition from Bronze to Iron Ages in Anatolia and its neighbouring regions: proceedings of the International Workshop, Istanbul, November 8-9, 2002. Istanbul: Türk Eskiçağ Bilimleri Enstitüsü.

Reimer, P. J., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Bronk Ramsey, C., Buck, C. E., Cheng, H., Edwards, R. L., Freidrich, M., Grootes, P. M., Guilderson, T. P., Hafildason, H. Hajdas, I., Hatte, C., Heaton, T. J., Hoffmann, D. L., Hogg, A. G., Hughen, K. A., Kaiser, K. F., Kromer, B., Manning, S. W., Niu, M., Reimer, R. W., Richards, D. A., Scott, E. M., Southon, J. R., Staff, R. A., Turney, C. S. M., and van der Plicht, J. 2013. IntCal13 and Marine 13 radiocarbon age calibration curves 0–50000 Years cal BP. Radiocarbon 55: 1869–1887.

Retamero, F. 1998. Un conjunto de reglas sabias y ordenadas. La disciplina agraria del sultan, pp.61-66 in C. Laliena Corbera and J.F. Utrilla Utrilla (eds.), De Toledo a Huesca: Sociedades Medievales en transición a finales del siglo XI (1080-1100). Zaragoza: Institución Fernando el Católico.

Retamero, F. 2009. La sombra alargada de Wittfogel. Irrigación y poder en al-Andalus, pp.263-293 in M. Marin (ed.), Al-Andalus/España. Historiografías en contraste. Siglos XVII–XXI. Madrid: Casa de Velázquez.

Rico C., Fabre, J-M., Polo Cutando, C. and Villagordo Ros, C. 2005. Recherches sur la sidérurgie ancienne dans la Sierra Menera (Teruel-Guadalajara). Bilan des travaux des années 2003-2004. Mélanges de la Casa de Velázquez 35: 345-353.

Riehl, S. 2009. Archaeobotanical evidence for the interrelationship of agricultural decision-making and climate change in the ancient Near East. Quaternary International 197: 93-114.

Riehl, S. 2010. Maintenance of agricultural stability in a changing environment: the archaeobotanical evidence at Emar, pp.177-224 in U. Finkbeiner and F. Sakal (eds.), Emar after the closure of the Tabqa dam: the Syrian-German excavations 1996-2002. Vol. 1. Turnhout: Brepols.

Riehl, S., Bryson, R. and Pustovoytov, K. 2008. Changing growing conditions for crops during the Near Eastern Bronze Age (3000–1200 BC): the stable carbon isotope evidence. Journal of Archaeological Science 35: 1011-1022.

Riehl, S., Pustovoytov, K.E., Weippert, H., Klett, S. and Hole, F. 2014. Drought stress variability in ancient Near Eastern agricultural systems evidenced by δ^{13}C in barley grain. Proceedings of the National Academy of Sciences 111: 12348-12353.

Rippon, S., Wainwright, A. and Smart, C. 2014. Farming regions in medieval England: the archaeobotanical and zooarchaeological evidence. Medieval Archaeology 58: 195-255.

Rizza, F., Ghashghaie, J., Meyer, S., Matteu, L., Mastrangelo, A.M. and Badeck, F.W., 2012. Constitutive differences in water use efficiency between two durum wheat cultivars. Field Crops Research, 125, pp.49-60.

Rodrigo Estevan, L. 2007. Claves de la expansión vitivinícola en el período medieval hispano: Aragón, siglos XII-XV". Universum, 22: 72-93.

Rodríguez Lajusticia, F S, 2015. Las sentencias arbitrales relacionadas con el regadío entre Magallón y la granja verolense de Mazalcoraz en los siglos XIV y XV: estado de la cuestión. Cuadernos de Estudios Borjanos 58: 169-203.

Rodríguez Lajusticia, F.S. 2008. Pleitos relacionados con el uso del agua en el monasterio Zaragozano de Veruela desde su fundación hasta el año 1400. Miscelánea Medieval Murciana 32:143-155.

Rodríguez Lajusticia, F.S. 2010. El dominio del monasterio cisterciense de Santa María de Veruela desde su fundación hasta 1400. Zaragoza: Institución Fernando el Católico.

Rodríguez Lajusticia, F.S. 2014. El regadío en Magallón (Zaragoza) hasta el siglo XV y la documentación medieval sobre agua conservada en su archivo municipal y sindicato de riegos. Aragón en la Edad Media 25: 239-272.

Rodríguez Lajusticia, F.S. 2019. Borja en época de Jaime I de Aragón según sus registros de cancillería (1252-1275). Cuadernos de Estudios Borjanos 62: 91-124.

Ros, J. and Ruas, M.P. 2017. Plantes de l'agriculture et de l'alimentation en Roussillon antique: les données carpologiques, pp.53-73 in N. Rovira, L. Bouby, A. Bouchette and M.P. Ruas (eds.) Plantes, Produits et pratiques: diffusion et adoption de la nouveauté dans les sociétés préindustrielles, Actes des Rencontres d'Archéobotanique 2010, 13-16 Octobre 2010. Lattes: ADALR.

Ros, J., Evin, A., Bouby, L. and Ruas, M.P. 2014b. Geometric morphometric analysis of grain shape and the identification of two-rowed barley (*Hordeum vulgare* subsp. *distichum* L.) in southern France. Journal of Archaeological Science 41: 568-575.

Ros, J., Garrido Garcia, J.A., Ruiz Alonso, M. and Gilotte, S. 2018. Bioarchaeological results from the House 1 at Albalat (Romangordo, Extremadura, Spain): agriculture, livestock and environment at the margin of al-Andalus. Journal of Islamic Archaeology 5: 71-102.

Ros, J., Puig, C. and Ruas, M.P. 2014a. Les denrées végétales dans le nord de la Catalogne d'après les sources historiques et archéobotaniques (Xe-XVe siècles): productions et échanges. Archéologie du Midi Médiéval, 32: 123-138.

Ros, J., Ruas, M.P. and Hallavant, C. 2019. Gestion des déchets agro-pastoraux et domestiques en France méditerranéenne médiévale: les dépôts archéobotaniques, pp.169-185 in M. Conesa and N. Poirier (eds.), Fumiers! Ordures! Gestion et usage des déchets dans les campagnes de l'Occident médiéval et modern. Toulouse: Presses Universitaires du Mirail.

Rottoli, M. 2014. Reflections on Early Medieval resources in northern Italy: the archaeobotanical and archaeozoological data. Quaternary international 346: 20-27.

Rowan, E. 2015. Olive oil pressing waste as a fuel source in antiquity. American Journal of Archaeology 119: 465-482.

Rowley-Conwy, P. 1989. Nubia AD 0-550 and the 'Islamic' agricultural revolution: preliminary botanical evidence from Qasr Ibrim, Egyptian Nubia. Archéologia du Nil Moyen 3: 131-138.

Royo, C., Martos, V., Ramdani, A., Villegas, D., Rharrabti, Y. and García del Moral, L.F. 2008. Changes in yield and carbon isotope discrimination of Italian and Spanish durum wheat during the 20th century. Agronomy Journal 100: 352-360.

Ruas, M.P. 2002. Productions agricoles, stockage, et finage en Montagne Noire médiévale: Le grenier castral de Durfort (Tarn). Paris: Éditions de la Maison des Sciences de l'Homme.

Ruas, M.P. 2005. Aspects of early medieval farming from sites in Mediterranean France. Vegetation History and Archaeobotany 14: 400-415.

Ruas, M.P. 2007. La parole des grains. Enquête archéobotanique sur l'engrain (*Triticum monococcum* L.) au Moyen Âge, pp.149-170 in A. Durand (ed.), Plantes exploitées, plantes cultivées. Cultures, techniques et discours. Etudes offertes à Georges Comet. Aix-en-Provence: Publications de l'Université de Provence.

Ruas, M.P., Bouby, L., Py, V. and Cazes, J.P. 2005a. An 11th century A. D. burnt granary at La Gravette, south-western France: preliminary archaeobotanical results. Vegetation History and Archaeobotany 14: 416-426.

Ruas, M.P., Bouby, L., Mane, P. Puig, C. and Pradat, B. 2005b. Les fruits de l'alimentation médiévale en France du Sud, entre marchés, recettes et dépotoirs. Archéologie du Midi Médiéval 23: 195-206.

Ruas, M.P., Mane, P., Puig, C., Hallavan, C., Pradat, B., Ouerfelli, M., Ros, J., Alexandre-Bidon, D. and Durand, A., 2015. Regard pluriel sur les plantes de l'héritage arabo-islamique en France médiévale. In Héritages arabo-islamiques dans l'Europe méditerranéenne, pp.347-376 in C. Richarté, R-P. Gayraud and J-M. Poisson (eds.) Héritages arabo-islamiques dans l'Europe méditerranéenne. Paris: La Découverte-INRAP.

Ruas, M.P., Tengberg, M., Ettahiri, A.S., Fili, A. and Van Staëvel, J.P. 2011. Archaeobotanical research at the medieval fortified site of Îgîlîz (Anti-Atlas, Morocco) with particular reference to the exploitation of the argan tree. Vegetation History and Archaeobotany 20: 419-433.

Rubio, A. 2002. Valencia y los aragoneses en la Baja Edad Media: la ruta del trigo. Caplletra 32: 95-110.

Sabato, D., Masi, A., Pepe, C., Ucchesu, M., Peña-Chocarro, L., Usai, A., Giachi, G., Capretti, C. and Bacchetta, G, 2015. Archaeobotanical analysis of a Bronze Age well from Sardinia: a wealth of knowledge. Plant Biosystems 149: 205-215.

Samsó, J. 2011. Las ciencias de los antiguos en al-Andalus Almería: Fundación Ibn Tufayl de Estudios Árabes.

Samuel, D. 2001. Archaeobotanical evidence and analysis, pp.343-481 in S. Berthier (ed.), Peuplement rural et aménagements hydroagricoles dans la moyenne vallée de l'Euphrate: fin du Vile -XIXe siècle. Damascus: Institut français d'études arabes de Damas.

Sánchez-López, G., Hernández, A., Pla-Rabès, S., Trigo, R.M., Toro, M., Granados, I., Sáez, A., Masqué, P., Pueyo, J.J., Rubio-Inglés, M.J. and Giralt, S. 2016. Climate reconstruction for the last two millennia in central Iberia: The role of East Atlantic (EA), North Atlantic Oscillation (NAO) and their interplay over the Iberian Peninsula. Quaternary Science Reviews 149: 135-150.

Sarasa Sánchez, E. 2013. La mesa del rey: Fernando I de Aragón (1412-1416), pp.11-20 in M. García Guatas, E. Piedrafita and J. Barbacil (eds.) La alimentación en la Corona de Aragón (siglos XIV-XV). Zaragoza: Institución Fernando el Católico

Sarr, B. 2013. Introducción al estudio del poblamiento beréber en la marca superior de al-Andalus (siglos VIII-XII). Mélanges de la Casa de Velázquez 43: 209-230.

Saura Gargallo, J. 2015. El paisaje agrario de Castellón de la Plana, pp.187-202 in C. Sanchis Ibor, G Palau Salvador, I. Mangue Alférez and L.P. Martínez-Sanmartín (eds.), Irrigation, Society and Landscape. Tribute to Tom F. Glick. València: Editorial Universitat Politècnica de València Hispana.

Schubert, B.A. and Jahren, A.H. 2012. The effect of atmospheric CO_2 concentration on carbon isotope fractionation in C3 land plants. Geochimica et Cosmochimica Acta 96: 29-43.

Scott, S.P. 1904. History of the Moorish empire in Europe (Vol.3). Philadelphia: Lippincott.

Sénac, P. 1998. Du hisn musulman au" castrum" chrétien le peuplement rural de la Marche supérieure et la Reconquête aragonaise, pp.113-130 in C. Laliena Corbera and J.F. Utrilla Utrilla (eds.), De Toledo a Huesca: Sociedades Medievales en transición a finales del siglo XI (1080-1100). Zaragoza: Institución Fernando el Católico.

Sénac, P. 2000. La frontière et les hommes (VIIIe-XIIe siècle): le peuplement musulman au nord de l'Ebre et les débuts de la reconquête aragonaise. Paris: Maisonneuve et Larose.

Sénac, P. 2008. Un "village" d'Al-Andalus aux alentours de l'an mil: Las Sillas, Marcén, province de Huesca. Tolouse: FRAMESPA.

Sénac, P. 2012. De la madîna à l'almunia: quelques réflexions autour du peuplement musulman au nord de l'Èbre. Annales du Midi 124: 183-201.

Serrano Martín, E. 1989. La agricultura aragonesa de los siglos XVI y XVII. Historia de Aragón 2: 113-122.

Servera-Vives, G., Riera, S., Picornell-Gelabert, L., Moffa-Sánchez, P., Llergo, Y., Garcia, A., Mus-Amezquita, M., Alvarez, S.G. and Trías, M.C. 2018. The onset of islandscapes in the Balearic Islands: A study-case of Addaia (northern Minorca, Spain). Palaeogeography, palaeoclimatology, palaeoecology, 498: 9-23.

Shaheen, R. and Hood-Nowotny, R.C. 2005. Effect of drought and salinity on carbon isotope discrimination in wheat cultivars. Plant Science 168: 901-909.

Sherratt, A., 2004. Cash-crops before cash: organic consumables and trade, pp.12-32 in C. Gosden and J.G. Hather (eds.), The Prehistory of Food. London: Routledge.

Shillito, L-M. and Almond, M.J. 2010. Comment on: Fruit and seed biomineralization and its effect on preservation by E. Messager et al.; in: Archaeological and Anthropological Sciences (2010) 2:25–34. Archaeological and Anthropological Sciences 2: 225-229.

Shillito, L-M., Almond, M.J., Nicholson, J., Pantos, M. and Mathews, W. 2009. Rapid characterisation of archaeological midden components using FT-IR spectroscopy, SEM-EDX and micro-XRD. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy 73: 133-139.

Smith, A., Dotzel, K., Fountain, J., Proctor, L. and von Baeyer, M. 2015. Examining fuel use in antiquity: archaeobotanical and anthracological approaches in southwest Asia. Ethnobiology Letters 6: 192-195.

Smith, H. and Jones, G. 1990. Experiments on the effects of charring on cultivated grape seeds. Journal of Archaeological Science 17: 317-327.

Smith, W. 1998. Fuel for thought: archaeobotanical evidence for the use of alternatives to wood fuel in Late Antique North Africa. Journal of Mediterranean Archaeology 11: 191-205.

Soller Milla, J.L., 2007. Comercio musulmán versus comercio cristiano: la actividad de los mercaderes mudéjares y la producción de las aljamas sarracenas. Valencia, primera mitad del siglo XIV. Anales de la Universidad de Alicante, Historia Medieval 14: 229-247.

Soller Milla, J.L. 2004. Relaciones comerciales entre Valencia y el Norte de África en la primera mitad del siglo xiv. Miscelánea Medieval Murciana, 27/28: 125-157.

Souto, J. 2006. Calatuyud: una madina en su context (siglos IX-X), pp.121-144 in in P. Sénac (ed.), De la Tarraconaise à la marche supérieure d'al-Andalus (IV-XI siècle): les habitats ruraux. Toulouse: Université de Toulouse-Le Mirail.

Souto, J.A. 1992. El poblamiento del término de Zaragoza (siglos VIII-X): los datos de las frentes geográficas e históricas. Anaquel de Estudios Arabes 3: 113-152.

Speleers, L. and van der Valk, J.M.A. 2017. Economic plants from medieval and post-medieval Brussels (Belgium), an overview of the archaeobotanical records. Quaternary International 436: 96-109.

Spengler, R.N. 2019. Dung burning in the archaeobotanical record of West Asia: where are we now?. Vegetation History and Archaeobotany 28: 215-227.

Spengler, R.N., Frachetti, M.D. and Fritz, G.J. 2013. Ecotopes and herd foraging practices in the steppe/mountain ecotone of Central Asia during the Bronze and Iron Ages. Journal of Ethnobiology 33: 125-148.

Squatriti, P. 2014a. Of seeds, seasons, and seas: Andrew Watson's medieval agrarian revolution forty years later. The Journal of Economic History 74: 1205-1220.

Squatriti, P. 2014b. The vegetative Mediterranean, pp.26-41 in P. Horden and S. Kinoshita (eds.), A comparison to Mediterranean history. Sussex: Wiley Blackwell.

Squatriti, P. 2016. Rye's Rise and Rome's Fall: Agriculture and Climate in Europe during Late Antiquity. Late Antique Archaeology 12: 160-169.

Stalls, C. 1995. Possessing the land: Aragon's expansion into Islam's Ebro frontier under Alfonso the Battler, 1104-1134. Leiden/New York: Brill.

Styring, A., Maier, U., Stephan, E., Schlichtherle, H. and Bogaard, A. 2016b. Cultivation of choice: new insights into farming practices at Neolithic lakeshore sites. Antiquity 90: 95-110.

Styring, A.K., Ater, M., Hmimsa, Y., Fraser, R., Miller, H., Neef, R., Pearson, J.A. and Bogaard, A. 2016a. Disentangling the effect of farming practice from aridity on crop stable isotope values: a present-day model from Morocco and its application to early farming sites in the eastern Mediterranean. The Anthropocene Review 3: 2-22.

Styring, A.K., Charles, M., Fantone, F., Hald, M.M., McMahon, A., Meadow, R.H., Nicholls, G.K., Patel, A.K., Pitre, M.C., Smith, A., Sołtysiak, A., Stein, G., Weber, J.A., Weiss, H. and Bogaard, A. 2017. Isotope evidence for agricultural extensification reveals how the world's first cities were fed. Nature Plants 3:17076.

Ṭāha, A.D. 1989. The Muslim conquest and settlement of North Africa and Spain. London: Routledge.

Tambussi, E.A., Bort, J. and Araus, J.L. 2007. Water use efficiency in C_3 cereals under Mediterranean conditions: a review of physiological aspects. Annals of Applied Biology 150: 307-321.

Teixeira, S. 1993. As granjas cistercienses do mosterio de Veruela e o repovamento do Vale do Huecha. Província de Zaragoza. IV Congreso de Arqueología Medieval Española 2: 459-465.

Teixeira, S. 1995. O sistems hidráulico do vale do Huecha sob o dominio do mosteiro de Veruela (Aragão). I Congresso de Arqueologia Peninsular, Sociedade Portuguesa de Antropologia e Etnologia 6: 383–402

Terral, J.F. and Durand, A. 2006. Bio-archaeological evidence of olive tree (*Olea europaea* L.) irrigation during the Middle Ages in Southern France and North Eastern Spain. Journal of Archaeological Science 33: 718-724.

Teulat, B., Merah, O. and This, D., 2001. Carbon isotope discrimination and productivity in field-grown barley genotypes. Journal of Agronomy and Crop Science 187: 33-39.

Tieszen, L.L. 1991. Natural variations in the carbon isotope values of plants: implications for archaeology, ecology, and paleoecology. Journal of Archaeological Science 18: 227-248.

Torró, J. 2009. Field and canal-building after the conquest: modifications to the cultivated ecosystem in the Kingdom of Valencia, ca.1250-ca.1350, pp.77-108 in B.A. Catlos (ed.), Worlds of history and economics: essays in honour of A.M. Watson. Valencia: Universitat de Valencia.

Torró, J. 2012. The eastern regions of al-Andalus before the conquest by Catalonia-Aragon: an overview. Catalan Historical Review 5: 11-27.

Torró, J. 2019. Paisajes de frontera: conquistas cristianas y transformaciones agrarias (siglos XII al XIV). Edad Media. Revista de Historia 20: 13-46.

Treasure, E.R., Brown, P.J., Gerrard, C.M. and Gutiérrez, A. in prep. Geophysical prospection at La Mora Encantada (Bulbuente) and Bureta/Los Pozos (Bureta). Unpublished Report.

Treasure, E.R., Church, M.J. and Gröcke, D.R., 2016. The influence of manuring on stable isotopes ($\delta^{13}C$ and $\delta^{15}N$) in Celtic bean (*Vicia faba* L.): archaeobotanical and palaeodietary implications. Archaeological and Anthropological Sciences 8: 555-562.

Trillo San José, C. 1999. El paisaje vegetal en la Granada Islámica y sus transformaciones tras la conquista castellana. Historia Agraria 17: 131-152.

Trillo San José, M.C. 2004. Agua, tierra y hombres en Al-Andalus la dimensión agrícola del mundo nazarí. Granada Grupo de Investigación "Toponimia, Historia y Arqueología del Reino de Granada."

Utrilla Utrilla, J.F. 1995. Los orígenes de la industria textil en Huesca: la construcción de los primeros molinos traperos (c. 1180-1190) y la creación de la cofradía de los tejedores oscenses (1239), pp.805-816 in Homenaje a Don Antonio Durán Gudiol. Huesca: Instituto de Estudios Altoaragoneses

Vaiglova, P., Bogaard, A., Collins, M., Cavanagh, W., Mee, C., Renard, J., Lamb, A., Gardeisen, A. and Fraser, R. 2014a. An integrated stable isotope study of plants and animals from Kouphovouno, southern Greece: a new look at Neolithic farming. Journal of Archaeological Science 42: 201-215.

Vaiglova, P., Snoeck, C., Nitsch, E., Bogaard, A. and Lee-Thorp, J. 2014b. Impact of contamination and pre-treatment on stable carbon and nitrogen isotopic composition of charred plant remains. Rapid Communications in Mass Spectrometry 28: 2497-2510.

Valamoti, S.M. 2011. Flax in Neolithic and Bronze Age Greece: archaeobotanical evidence. Vegetation History and Archaeobotany 20: 549-560.

Valamoti, S.M. and Charles, M. 2005. Distinguishing food from fodder through the study of charred plant remains: an experimental approach to dung-derived chaff. Vegetation History and Archaeobotany 14: 528-533.

Valamoti, S.M., Mangafa, M., Koukouli-Chrysanthaki, C. and Malamidou, D. 2007. Grape-pressings from northern Greece: the earliest wine in the Aegean?. Antiquity 81: 54-61.

Valamoti, S.M., Moniaki, A. and Karathanou, A. 2011. An investigation of processing and consumption of pulses among prehistoric societies: archaeobotanical, experimental and ethnographic evidence from Greece. Vegetation History and Archaeobotany 20: 381-396.

Vallvé, J. 1982. La agricultura en al-Andalus. Al-Qantara 3: 261-297.

van der Veen, M. 2007. Formation processes of desiccated and carbonized plant remains–the identification of routine practice. Journal of Archaeological Science 34: 968-990.

van der Veen, M. 2010. Agricultural innovation: invention and adoption or change and adaptation? World Archaeology, 42: 1-12.

van der Veen, M. 2011. Consumption, trade and innovation: exploring the botanical remains from the Roman and Islamic ports at Quseir al-Qadim, Egypt. Frankfurt am Main: Africa Magna Verlag.
van der Veen, M. and Fieller, N. 1982. Sampling seeds. Journal of Archaeological Science 9: 287-298.

Van der Veen, M. and Fieller, N. 1982. Sampling seeds. Journal of Archaeological Science 9: 287-298.

van der Veen, M. and Morales, J. 2017. Food globalisation and the Red Sea: new evidence from the ancient ports at Quseir al-Qadim, Egypt, pp.254-289 in D.A. Agius, E. Khalil, E.M.L. and A. Williams (eds.), Human Interaction with the Environment in the Red Sea. Selected Papers of Red Sea Project VI. Leiden: Brill.

van der Veen, M. 1999. The economic value of chaff and straw in arid and temperate zones. Vegetation History and Archaeobotany 8: 211-224.

van Der Veen, M., Hill, A. and Livarda, A. 2013. The archaeobotany of medieval Britain (c AD 450–1500): identifying research priorities for the 21st century. Medieval Archaeology 57: 151-182.

van der Veen, M., Livarda, A. and Hill, A., 2007. The archaeobotany of Roman Britain: current state and identification of research priorities. Britannia 38: 181-210.

van Leeuwaarden, W. and Querioz, P.F. 2003. Estudo de arqueobotânica no Castelo de Mértola. Unpublished report: Trabalhos do CIPA 23.

van Staëvel, J.P., Ruas, M.P., Ettahiri, A.S. and Fili, A. 2016. Lieux d'aisance et de toilette en milieu rural dans le Maroc médiéval: L'exemple des latrines du site d'Igīlīz et les déchets des plantes consommées. Médiévales 70: 189-213.

van Zeist, W., Bottema, S. and van der Veen, M. 2001. Diet and vegetation at ancient Carthage: the archaeobotanical evidence. Groningen: Groningen Institute of Archaeology.

Verde, A., Rivera, D. and Obón de Castro, C. 1998. Etnobotánica en las sierras de Segura y Alcaráz: las plantas y el hombre. Albacete: Instituto de Estudios Albacetences de la Excma.

Viciano, P., 2013. Endeudarse para consumir e invertir. La función económica de las obligaciones en una villa rural valenciana (Castellón de la Plana en 1499). Historia Agraria: Revista de Agricultura e Historia Rural 61: 13-44.

Vidal, J.P. 1973. La cultura de la caña de azúcar en el Levante español. Madrid: CSIC.

Vignola, C., Masi, A., Restelli, F.B., Frangipane, M., Marzaioli, F., Passariello, I., Stellato, L., Terrasi, F. and Sadori, L, 2017. $\delta^{13}C$ and $\delta^{15}N$ from ^{14}C-AMS dated cereal grains reveal agricultural practices during 4300–2000 BC at Arslantepe (Turkey). Review of Palaeobotany and Palynology 247: 164-174.

Viguera Molíns, M.J. 1994. Historia política, pp.32-121 in Viguera Molíns, M.J. (ed.), Historia de España. Los Reinos de Taifas: al-Andalus en el siglo XI. Madrid: Espasa Calpe.

Viguera Molíns, M.J. 1995. El Islam en Aragón. Zaragoza: Caja de Ahorros de la Inmaculada.

Viguera Molíns, M.J. 2010. Al-Andalus and the Maghrib (from the fifth/eleventh century to fall of the Almoravids, pp.21-47 in M. Fierro (ed.), The New Cambridge History of Islam: Volume 2. The Western Islamic World, Eleventh to Eighteenth Centuries. Cambridge: Cambridge University Press.

Vilagordo Ros, C. 2018. El proyecto de investigación "Ḥuṣūn y qurā: bases para un estudio del pasado andalusí en el sur de Aragón (ss. II/VIII-VI/XII). El poblamiento" (Museo de Teruel). Primeros resultados, pp.341-362 in J.M. Ortega Ortega (eds.), II Jornadas de Arqueología Medieval en Aragón: Reconstruir al-Andalus en Aragón. Teruel: Museo de Teruel.

Villargordo Ros, C. 2015. Excavaciones arqueológicas en el yacimiento Cabezo de la Cisterna (Alba del Campo, Teruel). Unpublished Report.

Villargordo Ros, C. 2016. Excavaciones arqueológicas en el yacimiento Cabezo de la Cisterna (Alba del Campo, Teruel). Unpublished Report.

Villargordo Ros, C. 2017. Excavaciones arqueológicas en el yacimiento El Quemao (Sarrión, Teruel). Unpublished Report.

Villargordo Ros, C. 2019. Excavaciones arqueológicas en el yacimiento El Quemao (Sarrión, Teruel). Unpublished Report.

Virgili, A. 2010. Espacios drenados andalusíes y la imposición de las pautas agrarias feudales en el prado de Tortosa (segunda mitad del siglo XII), pp.147-156 in H. Kirchner (ed.), Por una arqueología agraria: perspectivas de investigación sobre espacios de cultivo en las sociedades medievales hispánicas. Oxford: Archeopress (British Archaeological Reports International Series 2062).

Virgili, A., 2018. Campesinos y renta feudal en una sociedad colonial en construcción. La región de Tortosa, Tarragona (1148-1212). España Medieval 41: 23-48.

Vispe Martínez, J. 1984. La fundación del monasterio císterciense de Veruela y la construcción de su dominio monástico (1146-1174). Cistercium 167: 279-389.

Vogelzang, R.M. 2008. The book of Sent Soví: medieval recipes from Catalonia. Barcelona: Barcino

Voltas, J., Romagosa, I., Lafarga, A., Armesto, A.P., Sombrero, A. and Araus, J.L. 1999. Genotype by environment interaction for grain yield and carbon isotope discrimination of barley in Mediterranean Spain. Australian Journal of Agricultural Research 50: 1263-1271.

Waines, D. 1992. The culinary culture of al-Andalus, pp.725-740 in in S.M. Jayyusi (ed.), The Legacy of Muslim Spain. Leiden: Brill.

Waines, D. 2003. 'Luxury foods' in medieval Islamic societies. World Archaeology 34: 571-580.

Waines, D. 2010. The Odyssey of Ibn Battuta: Uncommon Tales of a Medieval Adventurer. Chicago: University of Chicago Press

Wallace, M. and Charles, M. 2013. What goes in does not always come out: the impact of the ruminant digestive system of sheep on plant material, and its importance for the interpretation of dung-derived archaeobotanical assemblages. Environmental Archaeology 18: 18-30.

Wallace, M., Jones, G., Charles, M., Fraser, R., Halstead, P., Heaton, T.H. and Bogaard, A. 2013. Stable carbon isotope analysis as a direct means of inferring crop water status and water management practices. World Archaeology 45: 388-409.

Wallace, M.P., Jones, G., Charles, M., Fraser, R., Heaton, T.H. and Bogaard, A. 2015. Stable carbon isotope evidence for Neolithic and Bronze Age crop water management in the eastern Mediterranean and southwest Asia. PloS one 10: e0127085.

Walshaw, S.C., 2010. Converting to rice: urbanization, Islamization and crops on Pemba Island, Tanzania, AD 700–1500. World Archaeology 42: 137-154.

Wasserstein, D. 1985. The rise and fall of the party-kings: politics and society in Islamic Spain, 1002-1086. New Jersey: Princeton University Press.

Watson, A.M. 1974. The Arab agricultural revolution and its diffusion, 700–1100. The Journal of Economic History 34: 8-35.

Watson, A.M., 1981. A medieval green revolution: new crops and farming techniques in the early Islamic world, pp.29-58 in A.L. Udovitch (ed.), The Islamic Middle East 700-1900. New Jersey: Darwin Press.

Watson, A.M. 1983. Agricultural innovation in the early Islamic world: the diffusion of crops and farming techniques, 700-1100. Cambridge: Cambridge University Press.

Watson, A.M. 1994. The imperfect transition of Arab agriculture into Christian Europe. Sitzungsberichte 619: 199-212.

Watson, A.M. 1995. Arab and European agriculture in the middle ages: a case of restricted diffusion, pp.62-75 in D. Sweeney (ed.) Agriculture in the Middle Ages: Technology, Practice, and Representation. Philadelphia: University of Pennsylvania Press.

Watson, A.M. 1998. Innovaciones en la agricultura en los primeros tiempos del mundo islámico: difusión de los distintos cultivos y técnicas agrícolas, del año 700 al 1100. Granada: Universidad de Granada.

Wetterstrom, W. 1994. Plantas carbonizadas, pp.483-510 in R.J. Harrison, G.C. Moreno López and A.J. Legge (eds.), Moncín: un poblado de la Edad del Bronce (Borja, Zaragoza). Zaragoza: Gobierno de Aragon, Departamento de Educación y Cultura.

Wickham, C. 1984. The other transition: from the ancient world to feudalism. Past and Present 103: 3-36.

Wickham, C. 2005. Framing the early Middle Ages: Europe and the Mediterranean, 400-800. Oxford: Oxford University Press.

Wickham, C. 2008. Productive forces and the economic logic of the feudal mode of production. Historical Materialism 16: 3-22.

Wilkinson, K. Gerrard, C.M., Pope, R. Aguilera, I. and Bailiff, I.K. 2005. Prehistoric and historic landscape change in Aragon, Spain: some results from the Moncayo Archaeological Survey. Journal of Mediterranean Archaeology 18: 31-54.

Wilkinson, T.J. 2016. Introduction, pp.1-16 in McPhillips, S. and Wordsworth, P.D. (eds.), Landscapes of the Islamic World: archaeology, history and ethnography. Philadelphia: University of Pennsylvania Press.

Wollstonecroft, M.M., Hroudová, Z., Hillman, G.C. and Fuller, D.Q. 2011. *Bolboschoenus glaucus* (Lam.) SG Smith, a new species in the flora of the ancient Near East. Vegetation History and Archaeobotany 20: 459-470.

Yang, J. and Zhang, J. 2006. Grain filling of cereals under soil drying. New Phytologist, 169: 223-236.

Zaouali, L. 2009. Medieval cuisine of the Islamic world. Berkley: University of California Press.

Zapata Peña, L. and Ruiz-Alonso, M. 2013. Agricultura altomedieval y usos forestales en Gasteiz (siglos VIII–XII d.C.). Datos carpológicos y antracológicos, pp.253-277 in A. Azkarate Garai-Olaun and J.L. Solaun Bustinza (eds.), Arqueología e historia de una ciudad. Los orígenes de Vitoria-Gasteiz. Bilbao: Servicio Editorial Universidad del País Vasco.

Zapata Peña, L., Peña-Chocarro, L., Ibáñez Estévez, J.J. and González Urquijo, J.E. 2003. Ethnoarchaeology in the Moroccan Jebala (Western Rif): wood and dung as fuel. Africa Praehistorica 15: 163-175.

Zohary, D., Hopf, M. and Weiss, E. 2012. Domestication of plants in the old world: the origin and spread of domesticated plants in Southwest Asia, Europe, and the Mediterranean Basin. Oxford: Oxford University Press.

The Frontier of Islam:

An Archaeobotanical Study of Agriculture in the Iberian Peninsula (c.700 – 1500 CE)

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Volume 2 of 2

Tables and Figures

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Figure 1.1: Map showing the location of the study areas within the north-east of the Iberian Peninsula. Stars 1a and 1b indicate the location of the Teruel study area (Islamic period sites). Star 2 indicates the location of the Huecha Valley, Zaragoza, study area (early medieval, Islamic and later medieval period sites). See Tables 2.1-2.2, Chapter 2, for further details on the sites investigated.

Figure 1.2: Map showing the areas of the Iberian Peninsula under Islamic rule between the c.9th-15th centuries, in the context of the wider early Islamic world in the c.9th-11th centuries. Illustration by the author, based on data in Kennedy (2002). Place names underlined in red were capitals of Taifa states (11th century).

Site	Period	Centuries	Site Description	Number of Samples	Sample Vol. (L.)
Cabezo de la Cisterna (CC16)	Islamic	11th-12th	Small rural settlement. Fortified tower, numerous structures/houses, large water cistern. *Feature/context types sampled: occupation deposits in houses.*	15	157
El Quemao (EQ17/18)	Islamic	10th-12th	Small rural settlement. Cluster of 9/10 houses, each with multiple rooms and a central courtyard. *Feature/context types sampled: floor/occupation deposits, ash-rich deposits, drain fill, silo fills.*	9	644

Table 2.1: Summary information of the sites sampled in Teruel (case-study area one), indicating location, period, number and volume (L) of samples.

Site	Period	Centuries	Site Description	Number of Samples	Sample Vol. (L.)
Bureta (BUR17)	Early medieval	6th-8th	Small rural settlement. Multiple phases of occupation in early medieval period. *Feature/context types sampled: occupation/floor surfaces, pit fills, ash-rich deposits, hearth/oven rake-outs, mixed refuse deposits.*	42	1134.2
La Mora Encantada (ME16)	Islamic	10th-12th	Small rural settlement. Fortified perimeter wall/tower, numerous structures, rock-cut silos. *Feature/context types sampled: ash-rich (conflagration?) deposits, occupation/floor surfaces, silo fills.*	12	570
Iglesia de Ambel (AC07)	Islamic	12th	Small fortified tower surrounded by silos in rural context, now a parish church. *Feature/context types sampled: silo fills, hearth, small tank.*	7	14.1
Palacio de Bulbuente (BULB14)	Later medieval	14th	Multi-period building complex (Abbot's palace), belonging to Cistercian monastery at Veruela. *Feature/context types sampled: major 14th century destruction/conflagration deposit and occupation deposits.*	52	481
Castillo de Grisel (GC16)	Later medieval	14th	Multi-period castle. *Feature/context types sampled: refuse deposits filling large, plaster-lined tank.*	2	122
Casa Conventual de Ambel (AP16)	Later medieval	15th	Multi-period building complex, belonging to Military Order (Hospitallers). *Feature/context types sampled: fill of large silo/cistern (refuse? deposits)*	4	375

Table 2.2: Summary information of the sites sampled in the Huecha Valley (case-study area two), indicating location, period, number and volume (L) of samples.

Latin name (Common name)
Cereals (exc. Millets)
Avena sp. (large >2mm, Oat)
Cerealia (indeterminate cereal)
Hordeum sp. (Barley)
Hordeum vulgare L. (Hulled Barley)
Hordeum vulgare var. *nudum* (Naked Barley)
Hordeum distichon L. (2-row Hulled Barley)
Hordeum vulgare L. (6-row Hulled Barley)
Secale cereale L. (Rye)
Triticum sp. (Wheat)
Triticum aestivum L./*durum* Desf. (Free-threshing Wheat)
Triticum aestivum L. (Bread-type Wheat)
Triticum dicoccon Schrank (Emmer Wheat)
Triticum durum Desf. (Durum-type Wheat)
Triticum monococcum L. (Einkorn Wheat)
Millets
Panicum miliaceum L. (Broomcorn Millet)
Setaria italica (L.) Beauv. (Foxtail Millet)
Fruits/Nuts
Celtis australis L. (Hackberry)
Corylus avellana L. (Hazel)
Ficus carica L. (Fig)
Morus alba/nigra L. (White/Black Mulberry)
Juglans regia L. (Walnut)
Olea europaea L. (Olive)
Prunus amygdalus Bätsch (Almond)
Prunus avium L. (Wild/Sweet Cherry)
Prunus cerasus L. (Sour Cherry)
Prunus persica (L.) Bätsch (Peach)
Vitis vinifera L. (Grape)
Pulses
Lathyrys cicera L. (Red Pea)
Lathyrus satvus L. (Grass Pea)
Lens culinaris Medicus (Lentil)
Pisum sativum L. (Pea)
Vicia ervilia (L.) Willd. (Bitter Vetch)
Vicia faba L. (Broad bean)
Oil/Fibre Crops
Linum usitatissimum L. (Flax)
Camelina sativa (L.) Crantz. (Gold-of-pleasure)
Other
Allium sativum L. (Garlic)

Table 2.3: Latin and common names for cereals, millets, fruits/nuts, pulses, oil/fibre crops and other crops analysed in this PhD research.

Taxa	Habitat/ Ecology	Annual/ Perennial	Onset period	Duration	Jan	Feb	Mar	Apr	May	Jun	Jul	Au	Sep	Oct	Nov	Dec
Agrostemma githago	Arable	Annual	Inter.	Long	-	-	-	(+)	(+)	(+)	+	+	+	+	-	-
Avena fatua	Arable	Annual	Inter.	Short	-	-	-	(+)	+	+	(+)	-	-	-	-	-
Carex sp.	Damp/wet ground	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Centaurea sp.	Arable	Annual	Inter.	Medium	-	-	-	-	+	+	+	+	+	-	-	-
Chenopodium album type	Ruderal	Annual	Early/Inter.	Long	-	-	-	-	+	+	+	+	+	+	+	(+)
Convolvulus arvensis	Ruderal	Perennial	Inter.	Medium	-	-	-	+	+	+	+	+	+	-	-	-
Fumaria sp.	Ruderal	Annual	Early/Inter.	Long	-	+	+	+	+	+	+	+	+	+	-	-
Galium aparine	Ruderal	Annual	Inter.	Short	-	-	-	-	-	+	+	+	+	+	-	-
Glaucium corniculatum	Arable/Ruderal	Annual	Inter.	Short	-	-	-	+	+	+	-	-	-	-	-	-
Hyoscyamus niger	Ruderal	Annual	Inter.	Medium	-	-	-	-	+	+	+	+	+	-	-	-
Lithospermum sp.	Arable/Wide niche	Annual	Early/Inter.	Long	-	-	+	+	+	+	+	+	+	-	-	-
Malva neglecta type	Ruderal	Annual	Early/Inter.	Long	-	-	+	+	+	+	+	+	+	+	-	-
Medicago arabica/polymorpha	Ruderal	Annual	Early/Inter.	Medium	-	-	+	+	+	+	+	-	-	-	-	-
Neslia apiculata/paniculata	Arable/Ruderal	Annual	Inter.	Short	-	-	-	+	+	+	-	-	-	-	-	-
Plantago lanceolata	Grassland/Ruderal	Annual	Inter.	Medium	-	-	-	+	+	+	+	+	+	-	-	-
Polygonum aviculare	Ruderal	Annual	Early/Inter.	Long	-	-	+	+	+	+	+	+	+	+	-	-
Polygonum convolvulus	Arable/Ruderal	Annual	Inter.	Medium	-	-	-	-	+	+	+	+	-	-	-	-
Portulaca oleracea	Ruderal	Annual	Early/Inter.	Long	-	-	(+)	+	+	+	+	+	+	+	(+)	-
Raphanus raphanistrum	Arable	Annual	Inter.	Medium	-	-	(+)	+	+	+	+	-	-	-	-	-
Setaria cf. *verticillata/viridis*	Ruderal	Annual	Late	Medium	-	-	-	-	-	-	+	+	+	+	+	-
Solanum nigrum	Ruderal	Annual	Inter.	Medium	-	-	-	-	+	+	+	+	+	+	-	-
Urtica pilulifera	Ruderal	Annual	Early/Inter.	Long	-	+	+	+	+	+	+	+	+	-	-	-
Vaccaria pyramidata	Arable	Annual	Inter.	Short	-	-	(+)	+	+	+	(+)	-	-	-	-	-

Table 2.4: Ecological information for wild/weed taxa (identified to species), classified according to habitat, annual/perennial life form, flowering onset period, duration of flowering period (adapted from Bogaard et al. 2001) and flowering months. '(+)' denotes less typical flowering period. 'Inter' refers to 'intermediate'. See text for references.

	Araus et al. (1997)	Wallace et al. (2013)	Riehl et al. (2014)	Flohr et al. (2019)	This PhD
Free-threshing wheat					
Well-watered	>17.5‰	>17‰	n/a	>17.5-18‰	>17‰ (16.8-19.5‰)
Moderately watered	n/a	16-17‰	n/a	n/a	n/a
Poorly watered	n/a	<16‰	n/a	c.<15‰	<17‰ (15.1-16.8‰)
Hulled barley					
Well-watered	>18‰	18.5‰	n/a	>18.5-19‰	>18.5‰ (18.0-19.7‰)
Moderately watered	n/a	17-18.5‰	n/a	n/a	n/a
Poorly watered	n/a	<17‰	<16-17‰	<16.5‰	<17‰ (15.2-19.2‰)

Table 2.5: Summary of interpretative models used to identify irrigation/drought stress based on cereal grain $\Delta^{13}C$ values. Data for free-threshing wheat grains, 2-row/6-row hulled barley grains. For simplicity, 'well-watered is used to refer to 'irrigated' defined by Araus et al. (1997), and 'poorly watered' is used to 'drought stress' defined by Riehl et al. (2014). Approximate water-status bands used in this PhD research, with numbers in parentheses indicating the range of values, see Figure 2.2 for details.

Studies	Broad bean		Lentil	
	Rainfed	Irrigated	Rainfed	Irrigated
Araus et al. (1997a)	14.9‰	16.7 ‰ (16.0-17.9‰)	-	-
Wallace et al. (2013)	16.1 ± 1.1‰	17.7 ± 1.5‰	14.8 ± 0.8‰ 16.0 ± 0.3‰	14.9 ± 0.4‰ 16.3 ± 0.3‰ 16.6 ± 0.6‰ 18.6 ± 0.5‰
Bogaard et al. (2018)	-	18.6 ± 0.2‰*	-	17.3 ± 0.2*
This PhD	<17‰	>17‰	<17‰	>17‰

Table 2.6: Relationship between $\Delta^{13}C$ values and irrigation for broad beans and lentils. Data within parenthesis indicates range. *Comparative data from Bogaard et al. (2018) for a sub-humid environment with high rainfall (703mm) in northern Morocco is also included to indicate $\Delta^{13}C$ values for well-watered broad beans and lentils. Approximate water-status bands used in this PhD research also indicated.

	Huecha Valley			Teruel
Site	Bureta	La Mora Encantada	Palacio de Bulbuente	El Quemao
Period	Early medieval (6th-8th)	Islamic (10th-12th)	Later medieval (14th)	Islamic (10th-12th)
Cereal grains				
Free-threshing wheat	5	19	35	25
Hulled barley	6	41	50	20
Rye	5	5	10	5
Emmer wheat	-	-	5	-
Cereal rachis segments				
Durum wheat	-	15	-	-
Bread wheat	-	9	-	-
Pulse seeds				
Broad beans	-	-	20	-
Lentils	-	5	-	10
Total	16	94	120	60

Table 2.7: Samples analysed in this PhD research for stable carbon isotope analysis. Note that only sites with large and well preserved assemblages have been selected for analysis.

Scale	Description	Charring temperature (°C): Cereal grains	Charring temperature (°C): Pulse seeds
P1	Perfect, no noticeable distortion	200-210°C	215°C
P2	Epidermis/testa virtually intact. Slight puffing noticeable.	220-240°C	215-260°C
P3	Epidermis/testa incomplete. Some distortion.	250°C	>260°C
P4-P6	Epidermis/testa incomplete. Clear/gross distortion. Clinkered.	>250°C	>260°C

Table 2.8: Scale used to record the preservation level for cereal grains, cereal rachis segments and pulse seeds for stable carbon isotope analysis. Most samples analysed fall into the 'P1-P2' category, none of the samples analysed are within the 'P4-P6' category. Adapted from Hubbard and al-Azm (1990), with *approximate* charring temperatures taken from Braadbaart et al. (2004), Braadbaart and van Bergen (2005), Charles et al. (2015), Nitsch et al. (2015). Comparative data for cereal rachis segments is not available and they are assumed to follow a similar pattern to cereal grains, though they are likely to be more sensitive to temperature changes (cf. Boardman and Jones 1990).

Figure 2.1: Excavation, sampling and flotation at La Mora Encantada, a 10th-12th century Islamic settlement near Bulbuente, Huecha Valley. Photographs by the author.

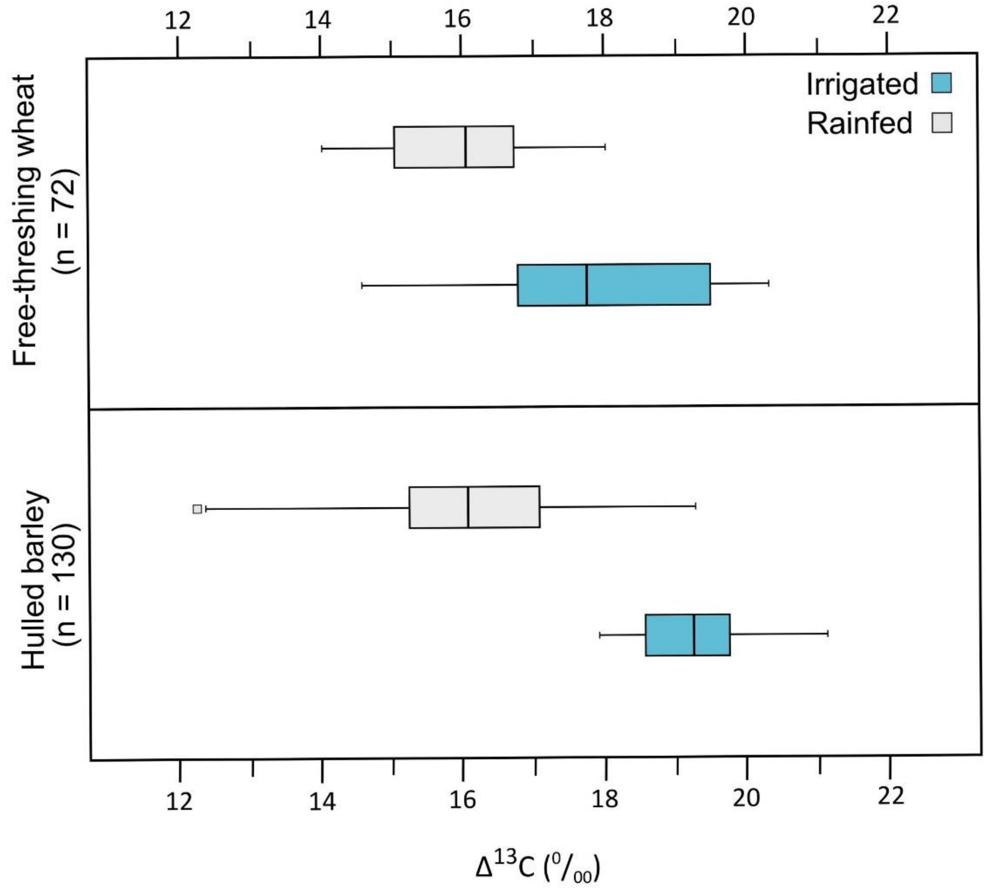


Figure 2.2: Box plots of $\Delta^{13}C$ values for free-threshing wheat and hulled barley cultivated under rainfed and irrigated conditions across the Mediterranean in semi-arid environments (NE Spain, SE Spain, Morocco, Syria, Jordan). Hulled barley *n*=130, with irrigated (*n*=32) and rainfed (*n*=98). Free-threshing wheat *n*=72, with irrigated (*n*=32) and rainfed (*n*=40). The whiskers reflect the minimum and maximum values, the grey/blue box reflects the interquartile range and the vertical black line reflects the median. Data compiled from: Craufurd et al. (1991), Araus et al. (1997a, 1997b, 2003), Merah et al. (1999), Voltas et al. (1999), Monneveux et al. (2006), Wallace et al. (2013), Fiorentino et al. (2012), Riehl et al. (2014), Bogaard et al. (2018), Flohr et al. (2019).

Sample	Trench	Context	Period	Centuries	Context type	Vol. (L)
1, 5	1	8	Islamic	11th-12th	Occupation deposit	16
2, 4	1	8	Islamic	11th-12th	Occupation deposit	17
3	1	3	Islamic	11th-12th	Occupation deposit	11
6	1	8	Islamic	11th-12th	Occupation deposit	15
7	1	3	Islamic	11th-12th	Occupation deposit	7
8	1	8	Islamic	11th-12th	Occupation deposit	14
9	3	18	Islamic	11th-12th	Occupation deposit	8
10	3	18	Islamic	11th-12th	Occupation deposit	5
11	3	18	Islamic	11th-12th	Occupation deposit	13
12	3	18	Islamic	11th-12th	Occupation deposit	6
13	3	25	Islamic	11th-12th	Occupation deposit	6
14	3	18	Islamic	11th-12th	Occupation deposit	12
15	3	25	Islamic	11th-12th	Occupation deposit	6
16	3	18	Islamic	11th-12th	Occupation deposit	13
17	3	18	Islamic	11th-12th	Occupation deposit	8
Total Sample Vol. (L)						157

Table 3.1: Details of the features/contexts sampled, Cabezo de la Cisterna. Compare with Figures 3.3-3.4.

		Sum
Cereal Grain		
Indet.	grain	49
Oat	grain	1
Barley	grain	5
Hulled barley	grain	4
Wheat	grain	3
Free-threshing wheat*	grain	10
Rye	grain	5
Cereal Chaff		
Indet	culm node	10
Indet.	rachis	2
Barley*	rachis	7
Free-threshing wheat	rachis	1
Rye	rachis	6
Millets		
cf. Foxtail millet	grain	1
Pulses		
Indeterminate	seed	1
Lentil*	seed	4
Bitter vetch	seed	1
Fruits/nuts		
Fig	seed	3
Mulberry	fruitstone	1
cf. Grape	pedicle	1
Other crops		
Flax	capsule (fg.)	3
Wild/weed taxa		
Asperula/Galium sp.	seed	7
Chenopodium album type	seed	1
Chenopodium sp.	seed	18
Fabaceae (<2mm)	seed	1
Galium sp.	seed	1
Medicago sp.	seed	1
Plantago sp.	seed	1
Poaceae spp. (>1mm)	caryopsis	13
Polygonaceae spp.	nutlet	1
Polygonum convolvulus	nutlet	1
Portulaca oleracea	seed	1
Rumex sp.	nutlet	1
Silene sp.	seed	1
Total count (charred)		166

Table 3.2: Summary of archaeobotanical evidence, Cabezo de la Cisterna. The symbol '*' indicates that plant remain includes 'cf.' identifications. Key to semi-quantitative scale: (+) = Trace, 1-5 items; + = Rare, 5-20 items; ++ = Occasional, 20-50; +++ = Common, 50-100; ++++ = Abundant, >100 items; +++++ = Extremely abundant, >500 items.

Sample	Area 1	Area 3
Contexts	3, 8	18, 25
Culm node: Grain	0.03	0.24
Rachis: Grain	0.13	0.29
Weed seeds: Grain	0.92	0.37

Table 3.3: Ratio calculations of chaff, weed seeds and grain, Cabezo de la Cisterna. Samples have been combined together for Areas 1 and 3, to ensure that the ratio calculations contain Ratios have only been calculated for samples containing >30 plant remains. There are too few grains/rachises of each cereal species to calculate separate ratios. Note the low ratios of chaff to grain, whilst the ratios of weed seeds to grain are slightly higher in area 1. Calculations based on van der Veen (2007).

Context	Sample	Sample Submitted	Uncalibrated Date (BP)	Calibrated Date (cal CE)	$\delta^{13}C$ ‰	Lab Number
(17-23)	4	Hulled barley grain	1095 ± 24	890-1000	-22.3	SUERC-88605
(18-11)	10	Free-threshing wheat grain	976 ± 24	1010-1160	-24.1	SUERC-88606

Table 3.4: Direct AMS ^{14}C dates obtained for this PhD. The location of SUERC-88605 is referred to in Figure 3.7. The location of SUERC-88606 is not visible in Figure 3.7.

Sample	Trench	Context	Period	Centuries	Context type	Vol. (L)
1	1	17-19	Islamic	10th-12th	Rubble/mixed occupation, fill of silo [17-18]	43
2	1	17-20	Islamic	10th-12th	Ash-rich deposit, fill of silo [17-18]	30
3	1	17-10	Islamic	10th-12th	Ash-rich occupation deposit	65
4	1	17-23	Islamic	10th-12th	Thick ash-rich deposit, fill of silo [17-18]	165
5	1	17-24	Islamic	10th-12th	Ash-rich deposit, fill of silo [17-18]	38
6	1	17-25	Islamic	10th-12th	Basal fill of silo [17-18]	31
7	1	17-21	Islamic	10th-12th	Ash-rich deposit, below floor surface	25
8	1	17-13	Islamic	10th-12th	Occupation deposit	40
9	1	17-8	Islamic	10th-12th	Ash-rich occupation deposit	42
10	1	18-19	Islamic	10th-12th	Ash-rich deposit	40
11	1	18-16	Islamic	10th-12th	Ash-rich (occupation?) deposit, NE of patio	20
12	5	18-16	Islamic	10th-12th	Ash-rich (occupation?) deposit, NW of patio	10
13	5	18-19	Islamic	10th-12th	Small ash-rich deposit	11
14	5	18-20	Islamic	10th-12th	Occupation/refuse deposit	21
17	5	18-23	Islamic	10th-12th	Small ash-rich deposit	5
18	5	18-25	Islamic	10th-12th	Floor/occupation surface	12
19	5	18-24	Islamic	10th-12th	Ash-rich deposit	10
20	5	18-34	Islamic	10th-12th	Ash-rich deposit, filling drain in patio	10
21	5	18-36	Islamic	10th-12th	Occupation/refuse deposit below floor surface (18-25)	17
22	5	18-37	Islamic	10th-12th	Occupation/floor surface below (18-36)	6
23	5	18-19	Islamic	10th-12th	Ash-rich deposit	3
Total Sample Vol. (L)						**644**

Table 3.5: Details of the features/contexts sampled, El Quemao. Compare with Figures 3.7-3.9.

		Sum			Sum
Cereal Grain					
Indet.	grain	1297	*Chenopodium album* type	seed	421
Barley*	grain	358	*Chenopodium* sp.	seed	18
Hulled barley*	grain	203	Fabaceae (<2mm)	seed	3
Wheat*	grain	59	*Fumaria* sp.	seed	1
Free-threshing wheat*	grain	321	*Galium* sp.	seed	52
Rye*	grain	64	cf. *Glaucium corniculatum*	seed	1
Emmer/Einkorn wheat	grain	2	cf. Lamiaceae	nutlet	164
Cereal Chaff			*Lithospermum* sp.	seed	27
Indet.	culm node	23	*Malva* sp.	seed	12
Indet.	rachis	42	*Medicago* sp.	seed	6
Barley	rachis	39	*Medicago/Meliotus*	seed	2
6-row hulled barley*	rachis	8	*Meliotus* sp.	seed	1
Free-threshing wheat	rachis	14	*Papaver* sp.	seed	5
cf. Bread wheat	rachis	1	cf. *Plantago* sp.	seed	4
Durum wheat*	rachis	12	Poaceae spp.	fl. base	2
Rye	rachis	119	Poaceae spp.	tw. awn	1
Wheat	spikelet fork	1	Poaceae spp. (<1mm)	caryopsis	138
Millets		252	Poaceae spp. (>1mm)	caryopsis	120
Broomcorn millet	grain	250	Polygonaceae spp.	nutlet	8
Broomcorn/Foxtail millet	grain	2	*Polygonum aviculare*	nutlet	1
Pulses			*Polygonum convolvulus*	nutlet	22
Indet.	seed	105	*Portulaca oleracea*	seed	8
cf. Red pea*	seed	18	Rubiaceae	seed	1
Lentil*	seed	164	*Setaria*	caryopsis	159
Pea (Type A)*	seed	54	*verticillata/viridis*		
Pea (Type B)*	seed	18	cf. *Setaria* sp.	caryopsis	26
Bitter vetch*	seed	13	*Silene* sp.	seed	41
Fruits/nuts			*Vicia* sp. (<2mm)	seed	7
Hackberry	fruitstone	3	**Mineralised remains**		
Fig*	seed	198	Fig	seed	37
Fig*	fruit (fg.)	13	Gold-of-pleasure	seed	2
Mulberry	fruitstone	3	Wheat	grain	3
Grape	pedicel	2	Indet. cereal	grain (fg.)	1
Grape	pip	6	Grape	seed/pip	4
Indet. fruitstone/nutshell	fg.	26	*Agrostemma githago* L.	seed	1
Other crops		3	cf. *Chenopodium* sp.	seed	1
Flax	seed	1	*Cirsium* sp.	achene	1
Flax	capsule (fg.)	1	Indeterminate/Unidentified		+
Garlic	clove	1	*Glaucium corniculatum*	seed	2
Wild/weed taxa			*Papaver* sp.	seed	10
Boraginaceae	seed	1	Poaceae spp. (<1mm)	caryopsis	1
Apiaceae	fruit	2	*Silene* sp.	seed	132
Apserula/Galium sp.	seed	1	*Silene* sp.	seed	132
Asperula sp.	seed	2	**Total count (charred)**		**4700**
Avena sp. <2mm)	caryopsis	2	**Total count (mineralised)**		**195**

Table 3.6: Summary of archaeobotanical evidence, El Quemao. The symbol '*' indicates that plant remain includes 'cf.' identifications. Key to semi-quantitative scale: (+) = Trace, 1-5 items; + = Rare, 5-20 items; ++ = Occasional, 20-50; +++ = Common, 50-100; ++++ = Abundant, >100 items; +++++ = Extremely abundant, >500 items.

Context	Centuries	Sample Type	*n*	Mean ($\Delta^{13}C$ ‰)	Min. ($\Delta^{13}C$ ‰)	Max. ($\Delta^{13}C$ ‰)
17-23/24*	10th	6-row hulled barley grain	10	17.0 ± 0.5	16.5	17.8
		Free-threshing wheat grain	10	15.9 ± 0.6	14.5	16.6
		Rye grain	5	16.3 ± 0.8	15.3	17.8
18-11	11th-12th	6-row hulled barley grain	10	17.7 ± 0.8	16.7	18.8
		Free-threshing wheat grain	10	16.4 ± 0.8	15.3	17.6
		Lentil seed	10	17.8 ± 0.8	16.4	18.9

Table 3.7: Stable isotope results, El Quemao, displaying the mean, minimum and maximum values. The symbol '*' denotes that samples come from closely related contexts within the same feature. *'n'* refers to number of single entity grain/seed samples analysed. Data plotted in Figure 3.11.

Sample	3	4	5	10	11	14	19	20
Context	17-10	17-23	17-24	18-11	18-16	18-20	18-24	18-34
Barley rachis: grain	1.6	0	0	0.1	1	0.3	0	0
Rye rachis: grain	30	0.3	-	8	6.8	-	-	-
Free-threshing wheat rachis: grain	0	0	0	0.1	6	0	0.1	-

Table 3.8: Ratio calculations of chaff and weed seeds to grain, El Quemao. Ratios have only been calculated for samples containing >30 charred remains. Note the high ratios of rye rachises in three samples. Compare with Figure 3.12.

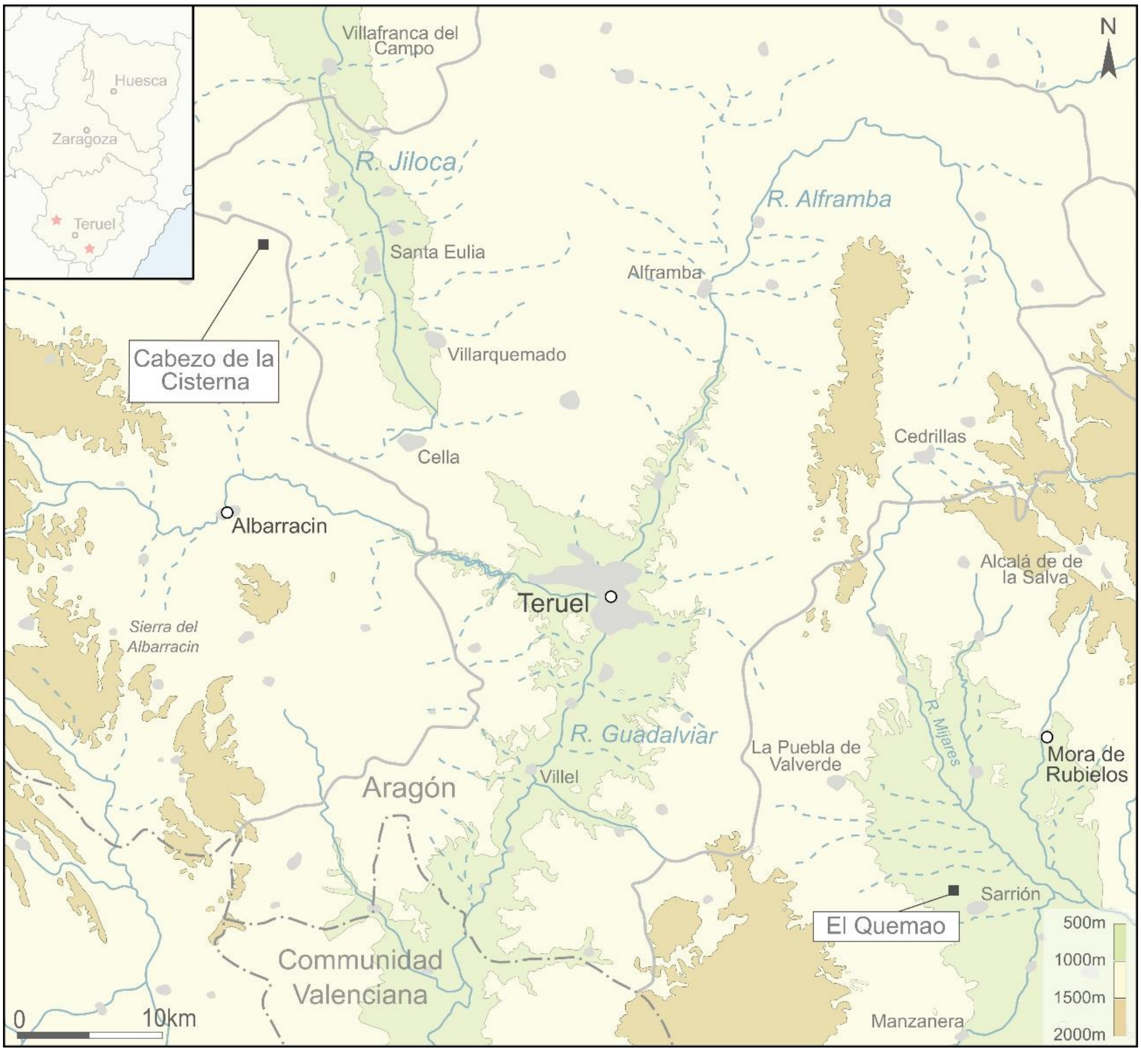


Figure 3.1: Map showing the location of the sites in the Teruel study area.

Figure 3.2: Aerial photograph showing the location of Cabezo de la Cisterna. (Google Earth 2019, base map).

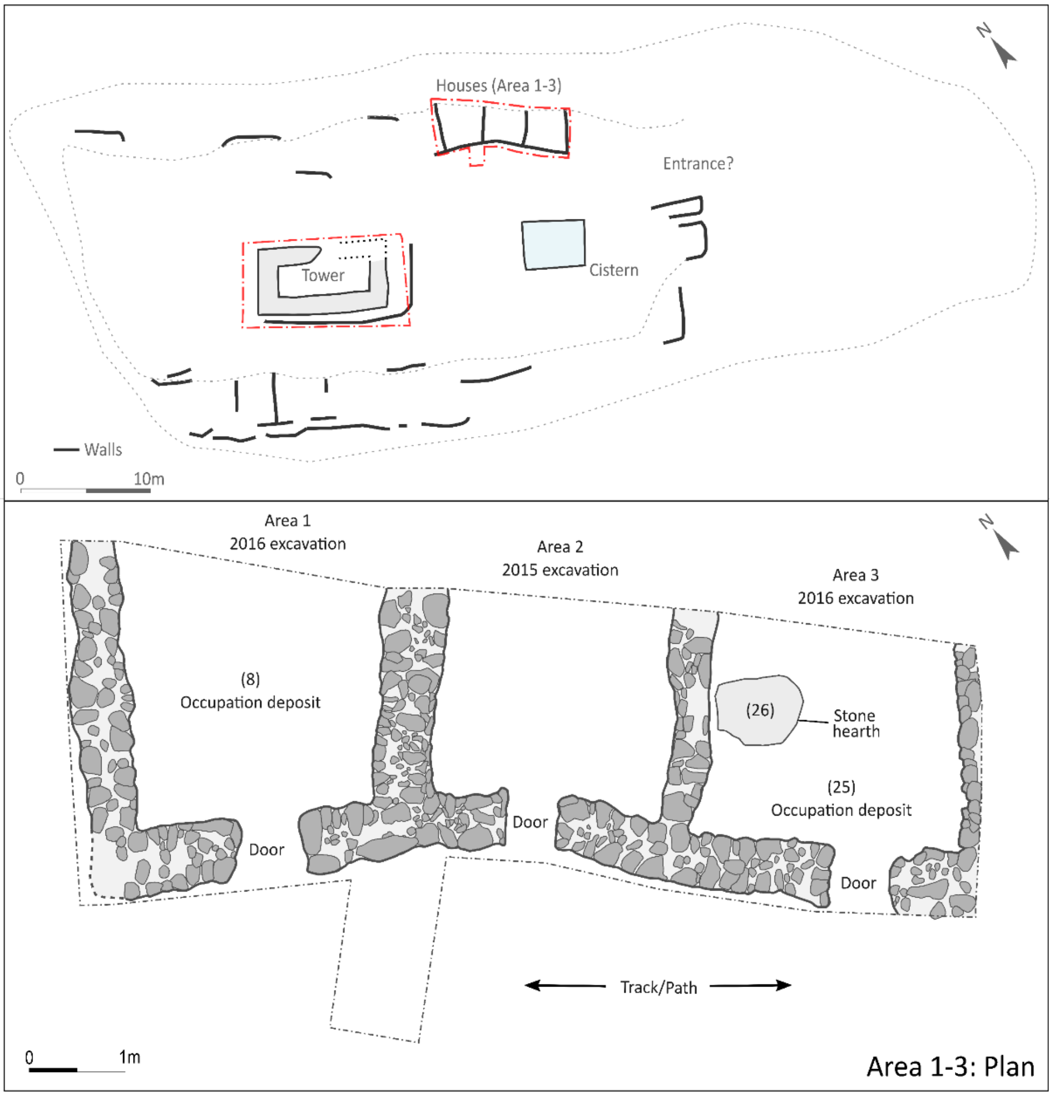


Figure 3.3: Site and Trench Plan, Cabezo de la Cisterna, indicating the houses excavated. Illustration by the author, adapted from Ortega Ortega (2008) and Villargordo Ros (2016).

Figure 3.4: Photographs of Area/House 3, Cabezo de la Cisterna. © C. Villargordo Ros.

Figure 3.5: Aerial photograph showing location of El Quemao. (Google Earth 2019, base map).

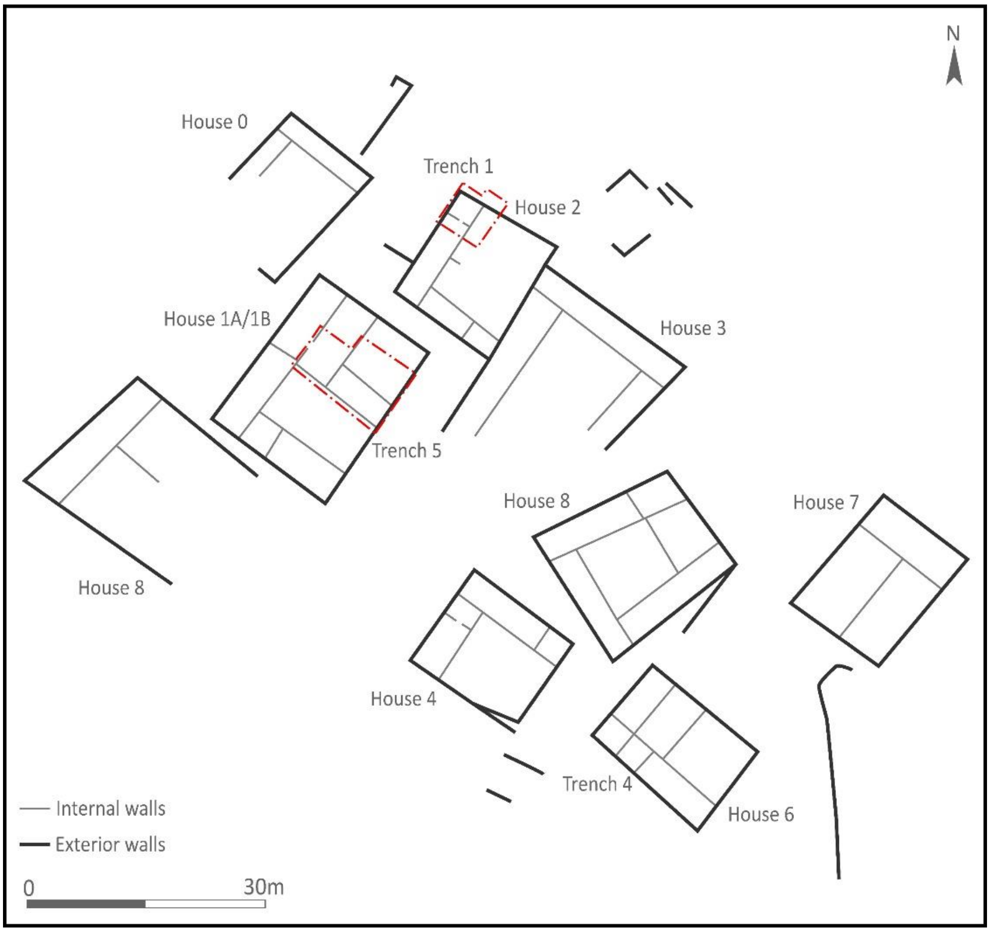


Figure 3.6: Site plan, El Quemao, indicating the courtyard houses and location of trenches where samples have been analysed. Illustration by the author, adapted from Villargordo Ros (2018).

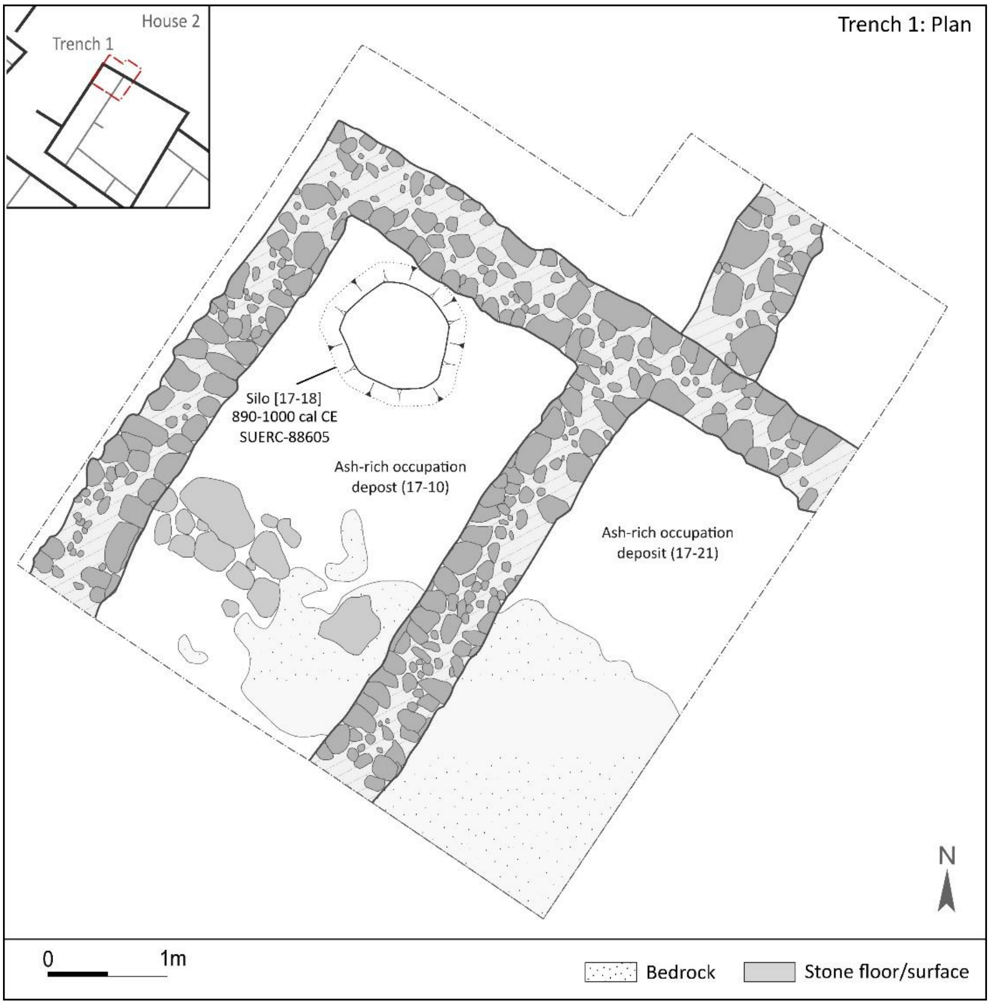


Figure 3.7: Trench 1 plan, El Quemao, indicated some of the contexts/features sampled. The fill of silo [17-18] is directly AMS ^{14}C dated to 890-1000 cal CE (SUERC-88605). Illustration by the author, adapted from Villargordo Ros (2018).

Figure 3.8: Trench 1 photographs, El Quemao, showing silo [17-18]. © C. Villargordo Ros.

Figure 3.9: General photograph of Trench 5, El Quemao, showing central courtyard with drain and associated rooms. Photograph by the author.

Figure 3.10: Photograph of charred garlic clove from context (11), sample 10. Photograph by the author.

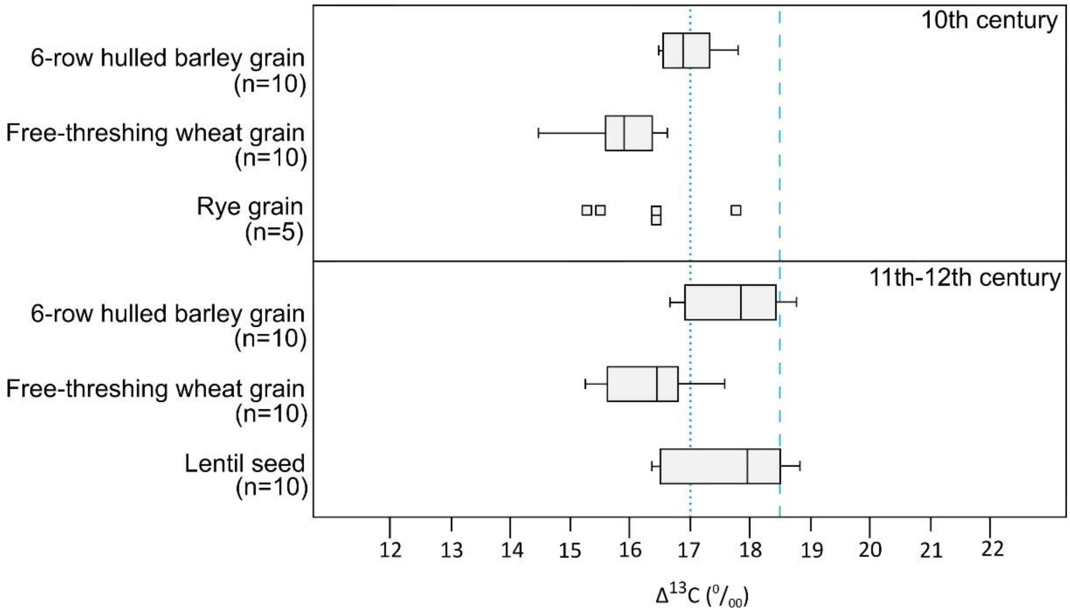


Figure 3.11: Stable isotope results, El Quemao. Samples with >5 items are represented by box-plots. The whiskers reflect the minimum and maximum values, the grey reflects the interquartile range and the vertical black line reflects the median. The dashed vertical line reflects 'well-watered' (irrigated) hulled barley, the dotted vertical line reflects 'well-watered' (irrigated) free-threshing wheat and lentil (see Wallace et al. 2013, Figure 2.2 and Tables 2.5-2.6). Mean, minimum and maximum values presented in Table 3.7.

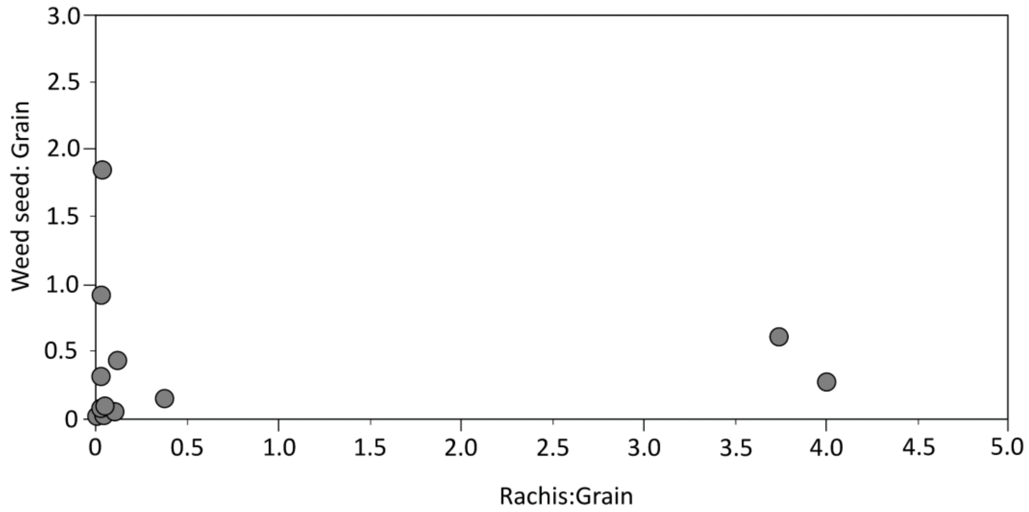


Figure 3.12: Ratios of weed seeds to grain, and rachis to grain, El Quemao. Ratios have only been calculated for samples containing >30 weed seeds/rachises/grains, calculated following van der Veen (2007). The clustering of samples in the bottom left reflect grain-rich samples, whilst the two samples (3, 11) separated on the X axis contain higher rations of rachises and the one sample (4) separated out on the Y axis contains a higher proportion of weed seeds. Compare with Table 3.8 for crop-specific ratios which are presented per sample.

Context	Sample	Sample Submitted	Uncalibrated Date (BP)	Calibrated Date (cal CE)	$\delta^{13}C$ ‰	Lab Number
(C5c)	6	Peach fruitstone	1481 ± 24	540-640	-28.0	SUERC-81225
(C27)	14	Wheat grain	1459 ± 21	560-650	-21.8	SUERC-81226
(P11)	27	Free-threshing wheat grain	1346 ± 29	640-770	-21.0	SUERC-80216
(P29/30)	42	Free-threshing wheat grain	1474 ± 24	550-640	-23.8	SUERC-81227

Table 4.1: Direct AMS ^{14}C dates, Bureta, obtained for this PhD. The locations of the samples are also referred to in Figures 4.7-4.9.

Sample	Trench	Context	Period	Centuries	Context type	Vol. (L)
1	C	C4A	Early med.	6th-7th	Fill of pit [C6]	32
2	C	C5A	Early med.	6th-7th	Fill of pit [C6]	31
5	C	C4C	Early med.	6th-7th	Fill of pit [C6]	18
6	C	C5C	Early med.	6th-7th	Fill of pit [C6]	57
9	C	C11	Early med.	6th-7th	Levelling deposit, below floor [C9]	57
10	C	C14	Early med.	6th-7th	Clay edge of pit [C6]	12
11	C	C15	Early med.	6th-7th	Occupation deposit	4
12	C	C18	Early med.	6th-7th	Burnt base of pit [C6]	39
13	C	C25	Early med.	6th-7th	Occupation deposit, below floor [C9]	60
14	C	C27	Early med.	6th-7th	Levelling deposit, below floor [C26]	58
15	C	C32	Early med.	6th-7th	Ash-rich fill of robber trench [C7]	44
16	C	C33	Early med.	6th-7th	Ash-rich fill of robber trench [C7]	58
17	C	C34	Early med.	6th-7th	Ash-rich fill of robber trench [C7]	42
18	C	C9	Early med.	6th-7th	Plaster floor	3
19	C	C52	Early med.	6th-7th	Ash-rich fill of pit [C61]	34
20	C	C53	Early med.	6th-7th	Ash-rich fill of pit [C61]	43
21	C	C54	Early med.	6th-7th	Ash-rich fill of pit [C61]	38
23	C	C59	Early med.	6th-7th	Clay floor surface?	5
24	C	C24	Early med.	6th-7th	Fill of plaster-lined pit [C22]	20
25	C	C8	Early med.	6th-7th	Plaster floor	14
26	C	C40	Early med.	6th-7th	Ash-rich fill of robber trench [C7]	45
27	P	P11	Early med.	7th-8th	Occupation deposit, next to wall [P10]	200
28	P	P15	Early med.	6th-7th	Charcoal-rich clay deposit, fill of pit [P37]	10
29	P	P43	Early med.	6th-7th	Ash-rich deposit, fill of pit [P37]	0.2
30	P	P18	Early med.	6th-7th	Ash-rich deposit, fill of pit [P37]	25
31	P	P19	Early med.	6th-7th	Clay/marl deposit, fill of pit [P37]	20
32	P	P20	Early med.	6th-7th	Ash-rich deposit, fill of pit [P37]	35
33	P	P22	Early med.	6th-7th	Ash-rich deposit, fill of pit [P37]	20
34	P	P23	Early med.	6th-7th	Clay/marl deposit, fill of pit [P37]	10
35	P	P24	Early med.	6th-7th	Charcoal flecked deposit, fill of pit [P37]	2
36	P	P25	Early med.	6th-7th	Ash-rich deposit, fill of pit [P37]	2
37	P	P26	Early med.	6th-7th	Ash-rich deposit, fill of pit [P37]	30
38	P	P28	Early med.	6th-7th	Sandy deposit, fill of pit [P37]	3

Sample	Trench	Context	Period	Centuries	Context type	Vol. (L)
39	P	P29	Early med.	6th-7th	Laminated sandy deposit, fill of pit [P37]	3
40	P	P27	Early med.	6th-7th	Laminated sandy deposit, fill of pit [P37]	4
41	P	P30	Early med.	6th-7th	Sandy deposit, fill of pit [P37]	5
42	P	P29/30	Early med.	6th-7th	Ash-rich deposit, fill of pit [P37]	2
43	P	P32	Early med.	6th-7th	Sandy charcoal-rich deposit, fill of pit [P37]	20
44	P	P33	Early med.	6th-7th	Sandy deposit, fill of pit [P37]	2
45	P	P12	Early med.	6th-7th	Fill of pit [P38], cut into pit [P37]	20
46	P	P16	Early med.	6th-7th	Sandy deposit, fill of pit [P37]	2
47	P	P14	Early med.	6th-7th	Fill of pit [P45], cut into pit [P37]	5
Total Sample Vol. (L)						**1134**

Table 4.2: Details of the features/contexts sampled, Bureta. Compare with Figures 4.6-4.7 for Trench C and Figures 4.8-4.9 for Trench P.

		Sum			Sum
Cereal Grain					
Indet.	grain	154	*Chenopodium album* type	seed	131
Oat	grain	2	*Chenopodium* sp.	seed	184
Barley*	grain	34	Fabaceae (<2mm)	seed	4
Hulled barley*	grain	25	*Galium aparine*	seed	1
Wheat*	grain	10	*Galium* sp.	seed	9
Free-threshing wheat*	grain	55	*Glaucium corniculatum*	seed	2
Rye*	grain	20	*Hippocrepsis* sp.	seed	4
Cereal Chaff			*Hyoscyamus niger*	seed	3
Indet	culm node	17	Lamiaceae	nutlet	2
Indet.	rachis	29	*Lithospermum* sp.	seed	2
Barley	rachis	34	*Malva neglecta* type	seed	5
2-row hulled barley*	rachis	8	*Malva* sp.	seed	3
6-row hulled barley	rachis	5	Malvaceae	seed	1
Free-threshing wheat	rachis	14	Medicago sp.*	seed	53
Bread wheat*	rachis	34	*Medicago/Meliotus*	seed	7
Rye	rachis	5	*Neslia apiculata/paniculata*	fruit	2
Emmer wheat	glume base	1	cf. *Plantago* sp.	seed	2
Millets			*Plantago lanceolata*	seed	2
Broomcorn millet	grain	2	Poaceae spp. (>1mm)	caryopsis	25
cf. Foxtail millet	grain	8	Poaceae spp. (<1mm)	caryopsis	90
Pulses			Polygonaceae spp.	nutlet	17
Indet.	seed	3	*Polygonum aviculare*	nutlet	5
cf. Lentil	seed	1	*Polygonum convolvulus*	nutlet	5
Grass pea	seed	8	*Portulaca oleracea*	seed	1
Bitter vetch	seed	1	*Raphanus raphanistrum*	pod	1
Fruits/nuts			Rubiaceae	seed	14
Indet. fruitstone/nutshell	fg.	2	*Rumex* sp.*	nutlet	8
Fig	seed	63	*Setaria* sp.	grain	3
Mulberry	fruitstone	1	*Silene* sp.	seed	9
Grape	pip	337	Solanaceae	seed	3
Grape	pedicel	71	*Stellaria* sp.	achene	1
Olive	fruitstone	7	*Urtica pilulifera*	achene	1
Peach	fruitstone	1	*Viola sp.*	seed	4
Wild/sour cherry	fruistone (fg.)	7	*Vicia* sp. (<2mm)	seed	3
Other crops			cf. *Viola* sp.	seed	1
cf. Flax	seed	1	**Other**		
Coriander	fruit/seed	1	Sheep/goat dung	pellets	++
Wild/weed taxa			**Mineralised remains**		
Agrostemma githago	seed	6	Gold-of-pleasure	seed	5
Amaranthaceae	seed	1	Wild cherry	fruitstone	1
Apiaceae	fruit	1	Grape	pip	7
Arctostaphylos uva-ursi	fruitstone	2	*Chenopodium* sp.	seed	18
Asperula/Galium sp.	seed	1	Indet./Unid. (inc. roots)		++
Asteraceae	achene	1	Lamiaceae	nutlet	1
Avena fatua	floret base	1	*Papaver* sp.	seed	1
Boraginaceae	seed	11	Poaceae (<1mm)	caryopsis	1
Carex spp.	nutlet	5	**Total count (charred)**		**1599**
Caryophyllaceae	seed	1	**Total count (mineralised)**		**31**

Table 4.3: Summary of the archaeobotanical evidence for Trench C and P, Bureta. The symbol '*' indicates that plant remain includes 'cf.' identifications. Key to semi-quantitative scale: (+) = Trace, 1-5 items; + = Rare, 5-20 items; ++ = Occasional, 20-50; +++ = Common, 50-100; ++++ = Abundant, >100 items; +++++ = Extremely abundant, >500 items.

Sample		15	16	17	19	20	21
Context		C32	C33	C34	C52	C53	C54
Trench/Area		C	C	C	C	C	C
Context Type		Ash-rich fill of robber trench [C7]			Ash-rich fill of pit [C61]		
Sample vol. (l)		44	58	42	34	43	38
Flot vol. (ml)		450	550	400	800	750	700
Charcoal ≥4mm		++++	++++	++++	++++	++++	++++
Charred Plant Remains							
Cereal Grain							
Indet. Cereal	grain	14	7	5	7	8	5
Barley*	grain	1	4	3	3	2	-
Hulled Barley	grain	-	-	-	1	1	-
Rye	grain	-	-	-	1	-	-
Wheat	grain	1	-	-	1	-	-
Free-threshing Wheat*	grain	5	3	3	5	-	-
Cereal Chaff							
Indet. Cereal	culm node	1	-	-	1	2	2
Indet. Cereal	rachis	1	-	-	-	2	7
Indet. Cereal	rachis (sub-)/basal	-	-	-	-	3	1
Barley	rachis	-	-	-	4	3	-
2-row Hulled Barley*	rachis	-	-	-	-	3	5
6-row Hulled Barley	rachis	2	-	-	-	-	-
Rye	rachis (sub-)/basal	-	-	-	1	-	-
Free-threshing Wheat	rachis	2	1	1	-	-	-
Free-threshing Wheat	rachis (sub-)/basal	1	-	-	-	-	-
Bread-type Wheat*	rachis	8	3	-	3	2	5
Millets							
cf. Foxtail Millet)	grain	2	-	1	2	-	-
Fruits/Nuts							
Hazel	nuthsell (fg.)	1	-	-	-	-	-
Fig	seed	-	2	-	-	1	-
Mulberry	fruitstone	-	-	-	1	-	-
Indeterminate fleshy fruit	(fg.)	-	(+)	-	-	-	-
Olive	fruitstone (fg.)	-	1	-	-	-	-
Wild/Sour Cherry	fruitstone (fg.)	-	-	1	-	-	2
Grape	seed/pip	8	13	5	5	2	1
Grape	pedicel	1	8	3	24	6	3
Pulses							
cf. Lentil	seed	1	-	-	-	-	-
Wild/weed taxa							
Agrostemma githago	seed	2	2	2	-	-	-
Amaranthaceae	seed	-	-	1	-	-	-
Apiaceae	fruit	-	-	-	-	-	1
Avena fatua	floret base	-	1	-	-	-	-
Boraginaceae	seed	2	9	-	-	-	-
Chenopodium album type	seed	4	6	8	-	12	4
Chenopodium sp.	seed	50	18	4	9	-	-
Fabaceae (small <2mm)	seed	-	1	-	-	-	1
Galium sp.	seed	-	2	3	-	-	-
Glaucium corniculatum	seed	-	-	-	2	-	-
Hippocrepsis sp.	seed	2	1	-	-	-	-
Hyoscyamus niger	seed	2	-	-	-	1	-
Lithospermum sp.	seed	1	1	-	-	-	-
Malva sp.	seed	-	1	-	-	-	-
Malvaceae	seed	-	-	-	1	-	-
Medicago sp.	seed	11	2	3	4	1	-
cf. *Medicago* sp.	seed	-	2	-	-	-	-
Medicago/Meliotus	seed	2	-	1	-	1	-
Neslia apiculata/paniculata	fruit	1	1	-	-	-	-
cf. *Plantago* sp.	seed	-	1	-	-	-	-

Sample		15	16	17	19	20	21
Context		C32	C33	C34	C52	C53	C54
Plantago lanceolata	seed	-	-	1	-	-	-
Poaceae spp. (large >1mm)	caryopsis	-	-	2	-	-	2
Poaceae spp. (small <1mm)	caryopsis	-	-	19	6	14	4
Polygonaceae spp.	nutlet	2	1	1	-	-	-
Polygonum aviculare	nutlet	-	1	-	-	-	-
Polygonum convolvulus	nutlet	2	1	1	-	-	-
Portulaca oleracea	seed	-	-	-	-	-	1
Rubiaceae	seed	5	-	-	4	3	-
Rumex sp.	nutlet	-	-	1	-	-	-
cf. *Rumex* sp.	nutlet	-	2	-	-	-	-
Silene sp.	seed	3	-	1	-	-	2
Solanaceae	seed	-	1	-	-	-	-
Urtica pilulifera	achene	1	-	-	-	-	-
Vaccaria pyramidata	seed	1	3	-	-	-	-
Vicia sp. (small <2mm)	seed	-	-	2	-	-	-
Viola sp.	seed	-	1	-	-	-	-
Mineralised Remains							
Gold-of-pleasure	seed	-	-	-	3	2	-
Indet. Cereal	grain (fg.)	-	1	-	-	-	-
cf. *Chenopodium* sp.	seed	-	-	-	-	-	1
Chenopodium sp.	seed	-	1	-	4	12	-
Indet./Unid. (inc. roots)		-	-	+	(+)	-	-
Papaver sp.	seed	-	-	-	1	-	-
Grape	seed/pip	-	2	-	-	-	-
Bio-mineralised Remains							
Boraginaceae	seed	2	1	-	-	-	1
Other Charred Plant Remains							
Fused charred material (conglomerations)		-	++	-	+++	+++	++
Indeterminate small <4mm leaves		-	-	-	(+)	-	-
Indeterminate/Unidentified		++	+	+	+	+	-
Monocotyledon stems (small <2mm)	culm node/base	+	-	-	(+)	-	-
Other Charred Non-Plant Remains							
Sheep/Goat dung	(fg.)	+	+	(+)	-	-	-
Other Mineralised Non-Plant Remains							
cf. Dog coprolite	(fg.)	-	-	-	(+)	-	-

Table 4.4: Summary of samples rich in crop processing debris and weeds, Bureta. Note that samples also include mineralised remains, sheep/goat dung and a probable dog coprolite. The symbol '*' indicates that plant remain includes 'cf.' identifications. Key to semi-quantitative scale: (+) = Trace, 1-5 items; + = Rare, 5-20 items; ++ = Occasional, 20-50; +++ = Common, 50-100; ++++ = Abundant, >100 items; +++++ = Extremely abundant, >500 items.

Context	Period/ Centuries	Sample Type	*n*	Mean ($\Delta^{13}C$ ‰)	Min. ($\Delta^{13}C$ ‰)	Max. ($\Delta^{13}C$ ‰)
P11	7^{th}-8^{th}	6-row hulled barley grain	6	17.0 ± 0.9	16.0	18.4
P18/24/26*	6^{th}-7^{th}	Free-threshing wheat grain	5	15.0 ± 1.2	13.4	16.37
P26	6^{th}-7^{th}	Rye grain	5	15.0 ± 2.6	12.6	18.5

Table 4.5: Stable isotope results, Bureta, displaying the mean, minimum and maximum values. The symbol '*' denotes that samples come from closely related contexts within the same feature. '*n*' refers to number of single entity grains analysed. Data plotted in Figure 4.11.

Context	Sample	Sample Submitted	Uncalibrated Date (BP)	Calibrated Date (cal CE)	$\delta^{13}C$ ‰	Lab Number
(4004)	1	Hulled barley grain	969 ± 28	1010-1160	-23.0	SUERC-74722
(1013)	7	Hulled barley grain	977 ± 28	990-1160	-21.9	SUERC-74723

Table 4.6: Direct AMS ^{14}C dates, La Mora Encantada, obtained as part of the Moncayo Archaeological Survey. The locations of the samples are indicated in Figures 4.14-4.15.

Sample	Trench	Context	Period	Centuries	Context type	Vol. (L)
1	4	4004	Islamic	10th-12th	Refuse deposit, base of silo 4	120
2	1	1003	Islamic	10th-12th	Ash-rich deposit, NW edge, top	6
3	1	1004	Islamic	10th-12th	Ash-rich deposit, NW edge, base	55
4	1	1007	Islamic	10th-12th	Ash-rich deposit, top	63
5	1	1011	Islamic	10th-12th	Ash-rich deposit, middle I	60
6	1	1012	Islamic	10th-12th	Ash-rich deposit, middle II	59
7/12	1	1013	Islamic	10th-12th	Ash-rich deposit, base	79
8	1	1015	Islamic	10th-12th	Floor/Occupation surface	27
9	1	1016	Islamic	10th-12th	Building/levelling deposit	36
10	3	3005	Islamic	10th-12th	Ash-rich deposit	40
11	5	5008	Later medieval?	14th?	Base of silo [5008]	20
Total Sample Vol. (L)						**570**

Table 4.7: Details of the features/contexts sampled, La Mora Encantada. Compare with Figures 4.14 and 4.16.

(Overleaf). Table 4.8: Summary of the charred archaeobotanical evidence, La Mora Encantada (excluding mineralised plant remains). The symbol '*' indicates that plant remain includes 'cf.' identifications. Key to semi-quantitative scale: (+) = Trace, 1-5 items; + = Rare, 5-20 items; ++ = Occasional, 20-50; +++ = Common, 50-100; ++++ = Abundant, >100 items; +++++ = Extremely abundant, >500 items.

		Sum			Sum
Cereal Grain					
Indet.	grain	108	*Avena* sp.	fl. base	2
Oat	grain	5	Boraginaceae	seed	2
Barley	grain	45	*Carex* spp.	nutlet	16
Hulled barley	grain	182	Caryophyllaceae	seed	2
cf. Naked barley	grain	3	*Centaurea* sp.	achene	2
Wheat	grain	26	*Chenopodium album* type	seed	57
Free-threshing wheat	grain	59	*Chenopodium* sp.	seed	143
Rye	grain	22	*Cirsium* sp.	achene	1
Cereal Chaff			*Convolvulus arvensis*	nutlet	1
Indet.	culm node	126	Cyperaceae	nutlet	2
Indet	culm/straw (fg.)	+++	Fabaceae (small <2mm)	seed	3
Indet.	lemma/palaea	17	*Fumaria* sp.	seed	2
Indet.	rachis	115	*Galium aparine*	seed	1
Barley	rachis	105	*Galium* sp.	seed	2
6-row hulled barley	rachis	113	*Hyoscyamus niger**	seed	6
Free-threshing wheat	rachis	81	cf. Lamiaceae	nutlet	2
Bread wheat	rachis	49	Lamiaceae	nutlet	1
Durum wheat	rachis	74	Wild *Linum* sp.	capsule (fg.)	1
Rye	rachis	79	*Lithospermum* sp.	seed	1
Millets			*Malva* sp.	seed	6
Broomcorn millet	grain	250	Malvaceae	seed	4
Broomcorn/Foxtail millet	grain	29	Medicago sp.*	fruit/pod	5
Foxtail millet	grain	15	Medicago sp.*	seed	13
Pulses			*Medicago/Meliotus* sp.	seed	1
Indet.	seed	6	*Meliotus* sp.	seed	3
Lentil	seed	10	*Papaver* sp.	seed	1
Pea	seed	1	Poaceae spp.	Fl. base	20
Grass/Red pea	seed	6	Poaceae spp.	tw. awn	7
Bitter vetch	seed	4	Poaceae spp. (<1mm)	caryopsis	31
Fruits/nuts			Poaceae spp. (>1mm)	caryopsis	313
Blackberry	fruitstone	206	Polygonaceae spp.	nutlet	5
cf. Pomegranate	seed	1	*Polygonum aviculare*	nutlet	1
Fig*	seed	435	*Polygonum convolvulus*	nutlet	2
Fig	fruit fg.	1	*Portulaca oleracea*	seed	1
Grape fruit/skin	berry/skin	35	*Raphanus raphanistrum*	pod/fruit	1
Grape pedicel	pedicel	185	cf. *Reseda* sp.	seed	51
Grape pip	pip	153	Rubiaceae	seed	4
Indet. fruitstone/nuts.	fg.	32	*Rumex* sp.	nutlet	5
Mulberry	fruitstone	22	*Sambucus* sp.	fruitstone	152
Olive	fruitstone	1	cf. *Sambucus* sp.	rachis	++
Walnut	nutshell (fg.)	201	*Silene* sp.	seed	14
Wild cherry	fruitstone	2	Solanaceae	seed	2
Wild/sour cherry	fruitstone (fg.)	14	*Solanum nigrum*	seed	2
Other crops			*Stellaria* sp.	achene	1
Flax	seed	65	cf. *Thalictrum* sp.	achene	4
Wild/weed taxa			*Vaccaria pyramidata**	seed	13
Agrostemma githago	seed	1	*Verbena officianalis*	seed	1
Amaranthaceae	seed	7	*Vicia* sp. (<2mm)	seed	2
Apiaceae	fruit	1	**Other**		
Apserula/Galium sp.	seed	1	Insect		+
Asteraceae spp.	achene	67	Textile	fg.	++
Atriplex sp.	seed	2			
Avena fatua	floret base	1	**Total count (charred)**		**3879**

Mineralised remains		
Fig	seed	1
Grape	pip	4
Broomcorn millet	grain	1
Wild cherry	fruitstone	1
Total count (mineralised)		**7**

Table 4.9: Summary of the mineralised archaeobotanical evidence, La Mora Encantada (excluding charred plant remains).

Context	Period/ Centuries	Sample Type	*n*	Mean ($\Delta^{13}C$ ‰)	Min. ($\Delta^{13}C$ ‰)	Max. ($\Delta^{13}C$ ‰)
1013*	10^{th}-12^{th}	6-row hulled barley grain	21	15.6 ± 1.5	13.3	18.2
		Free-threshing wheat grain	14	16.9 ± 0.9	15.3	18.1
		Rye grain	5	15.1 ± 1.0	13.6	16.3
		Bread wheat rachis	9	17.9 ± 1.9	15.0	20.2
		Durum wheat rachis	10	17.6 ± 1.5	15.7	20.0
		Lentil seed	5	16.1 ± 0.5	15.4	16.8
3005	10^{th}-12^{th}	6-row hulled barley grain	5	15.3 ± 1.1	13.8	16.5
		Free-threshing wheat grain	5	17.4 ± 1.1	15.9	18.5
		Durum wheat rachis	5	19.7 ± 0.5	19.2	20.7
4004	10^{th}-12^{th}	6-row hulled barley grain	15	15.8 ± 1.9	13.8	19.1

Table 4.10: Stable isotope results, La Mora Encantada, displaying the mean, minimum and maximum values. The symbol '*' denotes that samples come from closely related contexts within the same feature. *'n'* refers to number of single entity grain/seed/rachis samples analysed. Data plotted in Figure 4.19.

Sample	1	7/12	10
Context	4004	1013	3005
Culm node: Grain	0.01	0.82	0.27
Rachis: Grain	0.15	3.23	3.71
Weed seeds: Grain	0.41	3.83	4.56
Hulled Barley rachis: Grain	0.22	1.89	1.38
Rye rachis: Grain	-	3.55	3.00
Free-threshing wheat rachis: grain	0.06	5.75	4.64

Table 4.11: Ratio calculations of chaff and weed seeds to grain, La Mora Encantada. Ratios have only been calculated for samples containing >30 charred remains. Note the high ratios of rachises to grains and weed seeds to grains in samples 7/12 and 10 compared to sample 1. Calculations based on van der Veen (2007).

Sample	Trench	Context	Period	Centuries	Context type	Vol. (L)
1	-	S2 I	Islamic	12th	Fill of silo [S2], base	5
2	-	S2 II	Islamic	12th	Fill of silo [S2]	3
3	-	S9 I	Islamic	12th	Fill of silo [S9], base	1
4	-	S9 II	Islamic	12th	Fill of silo [S9]	1
5	-	C1	Islamic?	-	Fill of tank [C1]	2
6	-	H1	Islamic?	-	Hearth	0.1
7	-	H2	Islamic?	-	Area around hearth	2
Total Sample Vol. (L)						**14.1**

Table 4.12: Details of the features/contexts sampled, Iglesia de San Miguel de Ambel.

		Sum
Cereal Grain		
Indet.	grain	1
Free-threshing wheat	grain	1
Rye	grain	1
Cereal Chaff		
Culm nodes/bases		1
6-row hulled barley	rachis	1
Millets		
Broomcorn/Foxtail millet	grain	1
Fruits/nuts		
Indet. fleshy fruit	fg.	1
Grape pedicel	pedicel	1
Wild/weed taxa		
Chenopodium sp.	seed	1
Fabaceae (<2mm)	seed	1
Galium sp.	seed	4
Lithospermum sp.	seed	1
Malva sp.	seed	1
Papaver sp.	seed	2
Poaceae sp.	floret base	1
Mineralised remains		
Broomcorn millet	grain	1
Lamiaceae	nutlet	1
Total count (charred)		**19**
Total count (mineralised)		**2**

Table 4.13: Summary of archaeobotanical evidence, Iglesia de San Miguel de Ambel.

Context	Sample	Sample Submitted	Uncalibrated Date (BP)	Calibrated Date (cal CE)	$\delta^{13}C$ ‰	Lab Number
(B38)	12	Emmer wheat grain	704 ± 28	1260-1385	-20.7	SUERC-74721
(H104)	9	Oat grain	597 ± 34	1290-1420	-25.2	SUERC-68398
(H104)	9	Barley grain	708 ± 36	1220-1390	-26.4	SUERC-68397
(B500)	-	Elm roundwood charcoal	626 ± 34	1280-1400	-23.7	SUERC-68396

Table 4.14: Direct AMS ^{14}C dates, Palacio de Bulbuente, from different areas of the destruction/conflagration deposit. Obtained as part of the Moncayo Archaeological Survey. Contexts (H104) and (B500) date the mid-14th century destruction/conflagration deposit.

Sample	Trench	Context	Period	Centuries	Context type	Vol. (L)
8	H	H88	Later med.	14th-16th	Mixed deposit, terrace	15
9	H	H104	Later med.	14th	Burnt occupation layer	15
10	B	B38	Later med?	pre-14th?	Iron slag deposit, pit [B35/45]	0.5
11	B	B38	Later med?	pre-14th?	Iron slag deposit, pit [B35/45]	0.6
12/13	B	B38	Later med?	pre-14th?	Iron slag deposit, pit [B35/45]	0.7
14	B	B44	Later med?	pre-14th?	Iron slag deposit, pit [B35/45]	0.2
15	B	B34	Later med?	pre-14th?	Sand deposit, pit [B35/45]	1.5
16	B	B32	Later med?	pre-14th?	Charcoal layer, pit [B35/45]	1.5
17	B	B29	Later med?	pre-14th?	Iron slag deposit, pit [B35/45]	4
18	B	B51	Later med?	pre-14th?	Mixed deposit, pit [B35/45]	4
19	B	B53	Later med.	14th	Conflagration deposit	40
20	B	B57	Later med.	14th	Burnt occupation layer	30
21	Z	Z22 C-3	Later med.	14th	Burnt occupation layer	3
22	Z	Z22 D-2	Later med.	14th	Burnt occupation layer	10
23	Z	Z22 D-3	Later med.	14th	Burnt occupation layer	20
24	Z	Z22 D-4	Later med.	14th	Burnt occupation layer	11
25	Z	Z22 E-2	Later med.	14th	Burnt occupation layer	11
26	Z	Z22 E-3	Later med.	14th	Burnt occupation layer	13
27	Z	Z22 E-4	Later med.	14th	Burnt occupation layer	10
28	Z	Z22 D-5	Later med.	14th	Burnt occupation layer	3
29	Z	Z22 E-5	Later med.	14th	Burnt occupation layer	3
30	Z	Z7 D-2 III	Later med.	14th	Conflagration deposit, base	5
31	Z	Z7 D-3 III	Later med.	14th	Conflagration deposit, base	10
33	Z	Z7 E-5 III	Later med.	14th	Conflagration deposit, base	3
35	Z	Z7 E-3 III	Later med.	14th	Conflagration deposit, base	6
36	Z	Z7 E-2 III	Later med.	14th	Conflagration deposit, base	7
37	Z	Z7 E-1 III	Later med.	14th	Conflagration deposit, base	11
38	Z	Z7 D-5 III	Later med.	14th	Conflagration deposit, base	2
39	Z	Z7 C-3 II	Later med.	14th	Conflagration deposit, middle	5
40	Z	Z7 E-3 II	Later med.	14th	Conflagration deposit, middle	12
41	Z	Z7 E-2 II	Later med.	14th	Conflagration deposit, middle	10
42	Z	Z7 D-3 II	Later med.	14th	Conflagration deposit, middle	12
44	Z	Z7 E-2 II	Later med.	14th	Conflagration deposit, middle	11
45	Z	Z7 D-2 II	Later med.	14th	Conflagration deposit, middle	2
46	Z	Z7 E-1 II	Later med.	14th	Conflagration deposit, middle	14
47	Z	Z7 D-4 III	Later med.	14th	Conflagration deposit, base	14
48	Z	Z7 E-4 II	Later med.	14th	Conflagration deposit, middle	11
49	Z	Z7 E-5 II	Later med.	14th	Conflagration deposit, middle	5
50	Z	Z7 D-5 II	Later med.	14th	Conflagration deposit, middle	4

Sample	Trench	Context	Period	Centuries	Context type	Vol. (L)
51	Z	Z7 C-3 II	Later med.	14th	Conflagration deposit, middle	4
63	Z	Z7 D-4 II	Later med.	14th	Conflagration deposit, middle	13
64	Z	Z7 E-4 II	Later med.	14th	Conflagration deposit, middle	10
66	Z	Z7 E-2 II	Later med.	14th	Conflagration deposit, middle	9
67	Z	Z7 E-3 II	Later med.	14th	Conflagration deposit, middle	13
68	Z	Z7 D-3 II	Later med.	14th	Conflagration deposit, middle	10
74	Z	Z22 E-1	Later med.	14th	Burnt occupation layer	10
75	Z	Z7 C-3 II	Later med.	14th	Conflagration deposit, middle	10
76	Z	Z 7 E-1 II	Later med.	14th	Conflagration deposit, middle	10
77	Z	Z7 D-2 II	Later med.	14th	Conflagration deposit, middle	14
78	Z	Z7 E-4 III	Later med.	14th	Conflagration deposit, base	14
79	Z	Z7 E-4 II	Later med.	14th	Conflagration deposit, middle	10
80	Z	Z7 D-4 II	Later med.	14th	Conflagration deposit, middle	13
Total Sample Vol. (L)						**481**

Table 4.15: Details of the features/contexts sampled, Palacio de Bulbuente. Compare with Figure 4.24.

		Sum			Sum
Cereal Grain					
Indet.	grain	2115	Plum family	fruitstone (fg.)	1
Oat*	grain	197	Walnut	nutshell (fg.)	47
Barley	grain	146	Wild cherry	fruitstone	2
Hulled barley*	grain	810	Wild/sour cherry	fruistone (fg.)	47
cf. Naked barley	grain	2	**Other crops**		
Wheat	grain	260	Flax	seed	1
Free-threshing wheat*	grain	887	**Wild/weed taxa**		
Rye*	grain	1045	*Agrostemma githago*	seed	3
Emmer wheat*	grain	78	Amaranthaceae	seed	2
cf. Emmer/Einkorn	grain	14	*Avena fatua**	floret base	3
Cereal Chaff			*Avena* sp.	floret base	1
Culm nodes/bases		59	*Avena* sp. (<2mm)	caryopsis	16
Culm/straw frag.		+++	*Chenopodium* sp.	seed	34
Indet	rachis	22	Fabaceae (<2mm)	seed	3
Barley	rachis	8	*Fumaria* sp.	seed	4
6-row hulled barley	rachis	13	*Galium aparine*	seed	1
Free-threshing wheat	rachis	10	*Galium* sp.	seed	9
Bread wheat	rachis	7	*Malva neglecta* type	seed	40
Durum wheat	rachis	9	*Malva* sp.	seed	19
Rye	rachis	368	Malvaceae	seed	10
Millets			Medicago sp.*	seed	20
Broomcorn millet	grain	116	*Papaver* sp.	seed	4
Broomcorn/Foxtail millet	grain	2	*Plantago lanceolata*	seed	2
Foxtail millet	grain	1	Poaceae spp.	tw. awn	2
Pulses			Poaceae spp. (>1mm)	caryopsis	15
Indeterminate	seed	48	Poaceae spp. (<1mm)	caryopsis	10
Lentil	seed	22	Polygonaceae spp.	nutlet	5
Pea	seed	14	*Polygonum convolvulus*	nutlet	2
Broad bean	seed	104	Rubiaceae	seed	1
Fruits/nuts			*Rumex* sp.	nutlet	2
Almond	nutshell (fg.)	1	*Sambucus* sp.	fruitstone	13
Blackberry	fruitstone	4	*Silene* sp.	seed	3
Fig	seed	34	*Vicia* sp. (<2mm)	seed	29
Grape fruit/skin	berry	8	**Other**		
Grape*	berry (fg.)	11	Sheep/goat dung	pellets	(+)
Grape	pressed skin	1	Insects		+
Grape	pedicel	31	Textile	fg.	(+)
Grape	pip	182	**Mineralised remains**		
Indet. fruitstone/nuts.	fg.	50	Olive	fruitstone (fg.)	2
Mulberry	fruitstone	2	Grape	pip	6
Olive	fruitstone	2			
Peach	fruitstone	3	**Total count (mineralised)**		**8**
Peach	fruitstone (fg.)	3	**Total count (charred)**		**7040**

Table 4.16: Summary of archaeobotanical evidence, Palacio de Bulbuente. The symbol '*' indicates that plant remain includes 'cf.' identifications. Key to semi-quantitative scale: (+) = Trace, 1-5 items; + = Rare, 5-20 items; ++ = Occasional, 20-50; +++ = Common, 50-100; ++++ = Abundant, >100 items; +++++ = Extremely abundant, >500 items.

Context	Period/ Centuries	Sample Type	*n*	Mean ($\Delta^{13}C$ ‰)	Min. ($\Delta^{13}C$ ‰)	Max. ($\Delta^{13}C$ ‰)
Z7/22/B53/57*	Mid-14th	6-row hulled barley grain	50	17.8 ± 1.0	15.1	19.4
		Free-threshing wheat grain	35	17.0 ± 1.2	14.6	19.4
		Emmer wheat grain	5	17.0 ± 0.8	16.1	17.8
		Rye grain	10	17.0 ± 1.5	15.2	20.1
		Broad bean seed	20	18.4 ± 1.0	16.7	20.6

Table 4.17: Stable isotope results, Palacio de Bulbuente, displaying the mean, minimum and maximum values. The symbol '*' denotes that samples from multiple areas of the destruction/conflagration deposit have been combined. '*n*' refers to number of single entity grain/seed samples analysed. Data plotted in Figure 4.26.

Sample Number	Context	Rachis:Grain Hulled Barley	Rye	Free-threshing wheat
19	B53	0.00	0.03	0.01
20	B57	0.00	0.04	0.01
22	Z22 D-2	0.18	0.92	0.07
23	Z22 D-3	0.20	1.25	0.11
24	Z22 D-4	0.00	0.38	0.00
25	Z22 E-2	0.03	0.10	0.10
27	Z22 E-4	0.11	0.64	0.00
31	Z7 D-2 III	0.00	1.18	0.04
36	Z7 E-2 III	0.00	0.35	0.00
37	Z7 E-1 III	0.00	0.25	0.00
39	Z7 C-3 II	0.10	5.40	0.06
40	Z7 E-3 II	0.00	0.00	0.00
44	Z7 E-2 II	0.00	1.11	0.00
46	Z7 E-1 II	0.00	0.17	0.00
47	Z7 D-4 III	0.00	0.00	0.00
48	Z7 E-4 II	0.00	0.00	0.00
51	Z7 C-3 II	0.00	3.75	1.00
63	Z7 D-4 II	0.00	1.67	0.00
67	Z7 E-3 II	0.00	0.00	0.00
68	Z7 D-3 II	0.00	0.20	0.00
75	Z7 C-3 II	0.00	0.28	0.06
77	Z7 D-2 II	0.00	0.29	0.00

Table 4.18: Ratio calculations of chaff, weed seeds and grain, Palacio de Bulbuente. Ratios have only been calculated for samples containing >30 rachises/grains. Compare with Figure 4.27. Note the high ratios of rye rachises to grains, particularly in samples 39 and 51. Calculations based on van der Veen (2007).

Sample	Trench	Context	Period	Centuries	Context type	Vol. (L)
1	Tank 1	1003	Later medieval	14th	Refuse deposit (upper)	86
2	Tank 2	1004	Later medieval	14th	Refuse deposit (lower)	36
Total Sample Vol. (L)						122

Table 4.19: Details of the features/contexts sampled, Castillo de Grisel. Compare with Figure 4.29.

		Sum
Cereal Grain		
Indet.	grain	5
Free-threshing wheat	grain	2
Oat	grain	1
Barley	grain	3
Hulled barley	grain	2
Wheat	grain	4
Free-threshing wheat	grain	2
Cereal Chaff		
Free-threshing wheat	rachis	2
Indet.	rachis	2
Millets		
Broomcorn millet*	grain	3
Pulses		
Indet.	seed	3
Pea	seed	1
Fruits/nuts		
Fig	seed	2
Grape	pedicel	1
Grape	pip	1
Grape	berry	6
Grape*	berry (fg.)	
Indet. fleshy fruit	fg.	1
Indet. fruitstone/nutshell	fg.	3
Walnut	nutshell (fg.)	6
Other crops		
Flax*	seed	24
Wild/weed taxa		
Agrostemma githago	seed	1
Chenopodium sp.	seed	1
Poaceae sp.	twisted awn	8
Poaceae spp. (>1mm)	caryopsis	2
Rumex sp.	nutlet	1
Thalictrum cf. *flavum*	achene	1
Mineralised remains		
Fig	seed	1
Grape	pip	3
Indet.		(+)
Total count (mineralised)		4
Total count (charred)		86

Table 4.20: Summary of archaeobotanical evidence, Castillo de Grisel. The symbol '*' indicates that plant remain includes 'cf.' identifications.

Sample	Trench	Context	Period	Centuries	Context type	Vol. (L)
1	-	42	Later medieval	15th	Fill of silo/cistern	150
2	-	44	Later medieval	15th	Fill of silo/cistern	80
3	-	46	Later medieval	15th	Fill of silo/cistern	65
4	-	47	Later medieval	15th	Fill of silo/cistern	80
Total Sample Vol. (L)						375

Table 4.21: Details of the features/contexts sampled, Casa Conventual de Ambel.

		Sum
Cereal Grain		
Indet.	grain	3
Wheat	grain	1
Hulled barley	grain	1
Rye	grain	1
Cereal Chaff		
Culm node		1
Millets		
Broomcorn/Foxtail millet	grain	1
Pulses		
Indet.	seed	1
Pea	seed	1
Other crops		
Flax	seed	2
Fruits/nuts		
Indet. fleshy fruit	fg.	1
Walnut	nutshell (fg.)	1
Olive	nutshell (fg.)	1
Grape	pip	4
Grape	berry	
Grape*	berry (fg)	17
Mineralised remains		
Indet.		(+)
Grape	pip	3
Total count (mineralised)		3
Total count (charred)		36

Table 4.22: Summary of archaeobotanical evidence, Casa Conventual de Ambel. The symbol '*' indicates that plant remain includes 'cf.' identifications. Key to semi-quantitative scale: (+) = Trace, 1-5.

Figure 4.1: Map showing the location of the sites in the Huecha Valley (Zaragoza) study area.

Figure 4.2: Photograph showing Huecha Valley study area. Monacyo is visible in the background, whilst the foreground shows vines, almonds, and rainfed cereal fields. Photograph by the author.

Figure 4.3: Photograph showing Huecha Valley study area, looking towards Borja. The foreground shows olive groves. Photograph by the author.

Figure 4.4: Aerial photograph showing the location of Bureta. (Google Earth 2019, base map).

Figure 4.5. Drone photograph of Bureta during excavation. Trench C is located at the top of the photograph, whilst Trench P is in the foreground. Photograph © C. Gerrard.

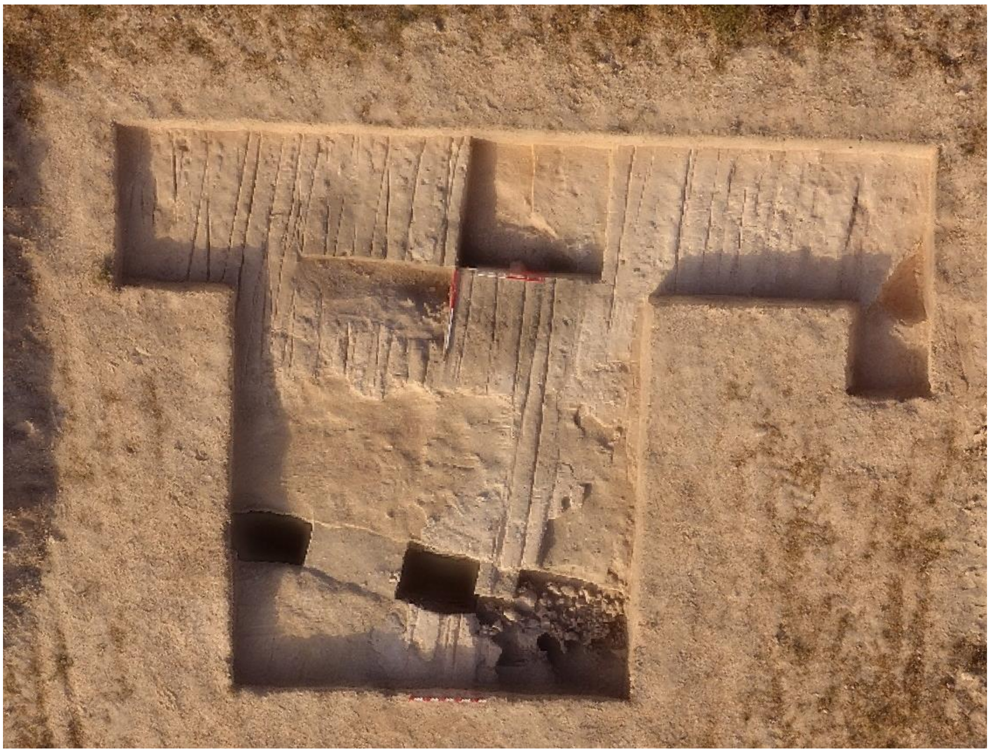


Figure 4.6: Drone photograph of Trench C, Bureta. The scale bars are positioned over pit [C6] which cuts through a plaster floor surface. The linear feature running diagonally across the bottom of the trench is wall-cut/robber trench C7, which also cuts through earlier plaster floor surfaces. Photograph © C. Gerrard.

Figure 4.7: Photographs of features/contexts sampled in Trench C, Bureta. A: Pit [C6] directly AMS ^{14}C dated to 540-640 cal CE (SUERC-81225), B: Wall-cut/robber trench [C7], C: Pit [C61], and D: Detail of earlier floor surfaces and occupation deposits visible the section of wall-cut [C7], including a plaster floor surface building/levelling deposit (C11) below a plaster floor, ash-rich occupation deposit (C25), plaster floor surface (C26), building/levelling deposit (C27) directly AMS ^{14}C dated to 560-650 cal CE (SUERC-81226) and natural geology (C28). Photographs A, B, D by the author, photograph C © C. Gerrard.

Figure 4.8: Photographs of features/contexts sampled in Trench P, Bureta. A: charcoal-rich occupation deposit (P11) directly AMS ^{14}C dated to 640-770 cal CE (SUERC-80216); B; pit [P37]; C: detail of ash-rich deposits between clay/marl lenses in pit [P37], directly AMS ^{14}C dated to 550-640 cal CE (SUERC-81227). Compare with Table 4.1. Photograph A by the author, photographs B and C © C. Gerrard.

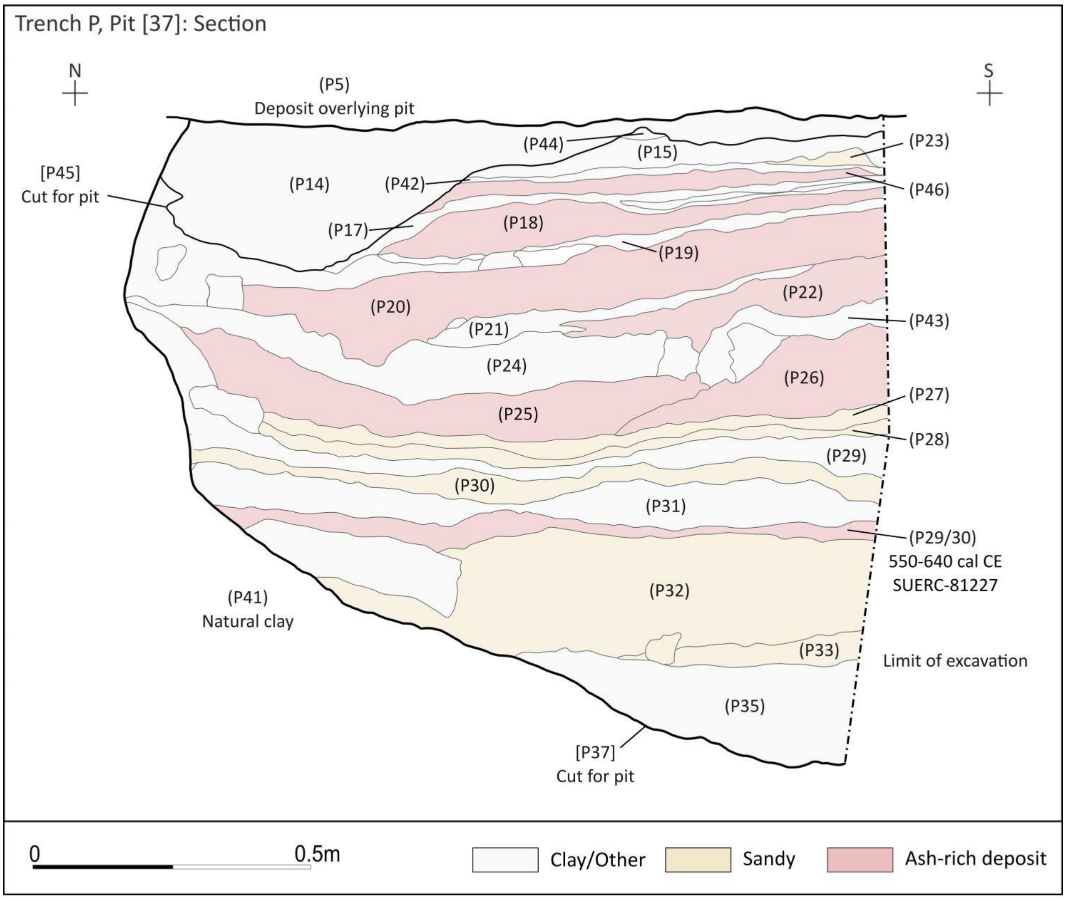


Figure 4.9: Simplified section drawing of pit [P37] in Trench P, Bureta. Basal fill directly AMS ^{14}C dated to 550-640 cal CE (SUERC-81227). Compare with Table 4.1. Illustration by the author, adapted from Gutiérrez and Gerrard (2019).

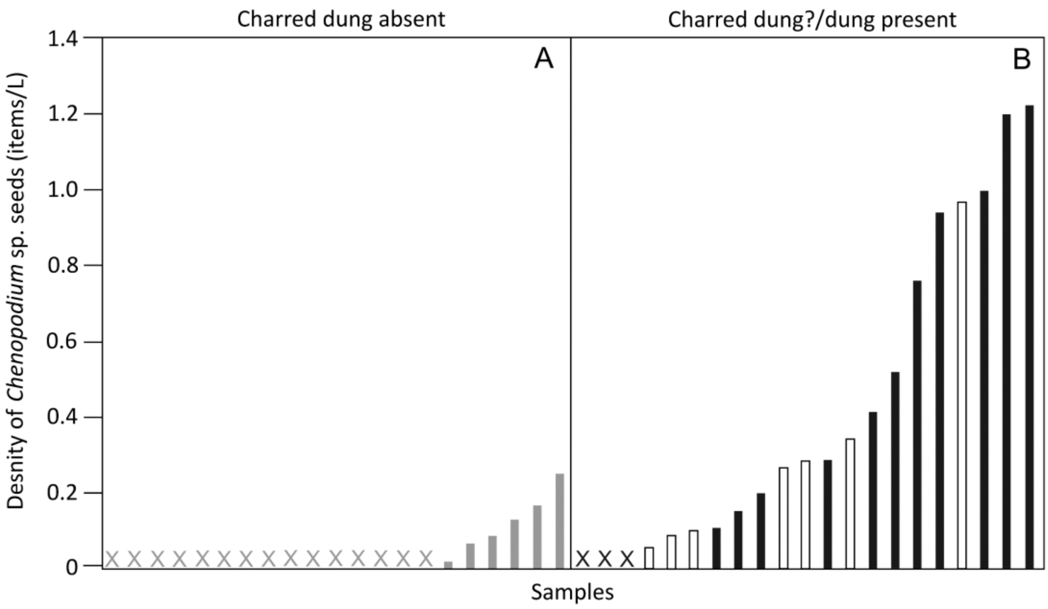


Figure 4.10: Relationship between *Chenopodium* sp. (items/L) and sheep/goat dung. Each bar represents an individual sample, with 'X' indicating that *Chenopodium* sp. seeds are absent. A=samples where sheep/goat dung is absent (light grey bars). B = samples where possible dung?/conglomerations (white bars) and definite sheep/goat dung (black bars). It should be noted that no charred plant remains were present in 6 samples.

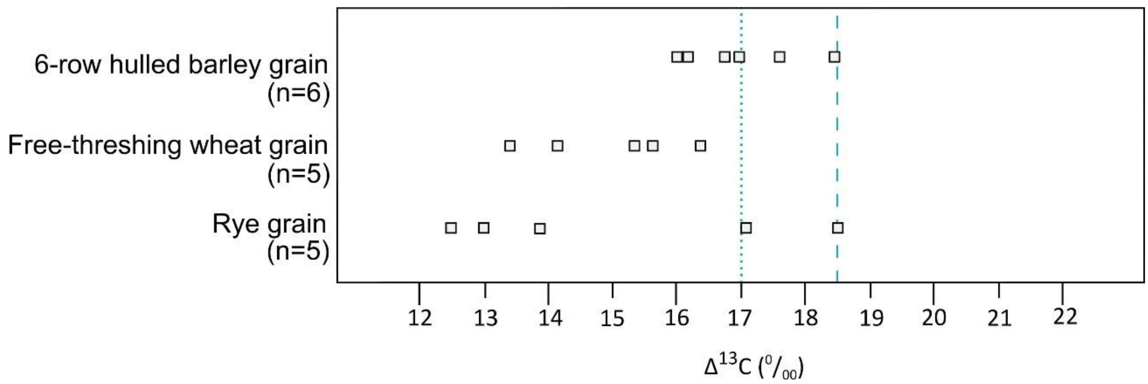


Figure 4.11: Stable isotope results, Bureta. The dashed vertical line reflects 'well-watered' (irrigated) hulled barley, the dotted vertical line reflects 'well-watered' (irrigated) free-threshing wheat (see Wallace et al. 2013, Figure 2.2 and Table 2.5). For mean, minimum and maximum values see Table 4.5.

Figure 4.12: Aerial photograph showing the location of La Mora Encantada. (Google Earth 2019, base map).

Figure 4.13: Drone photographs showing trench locations, La Mora Encantada. Photograph © C. Gerrard.

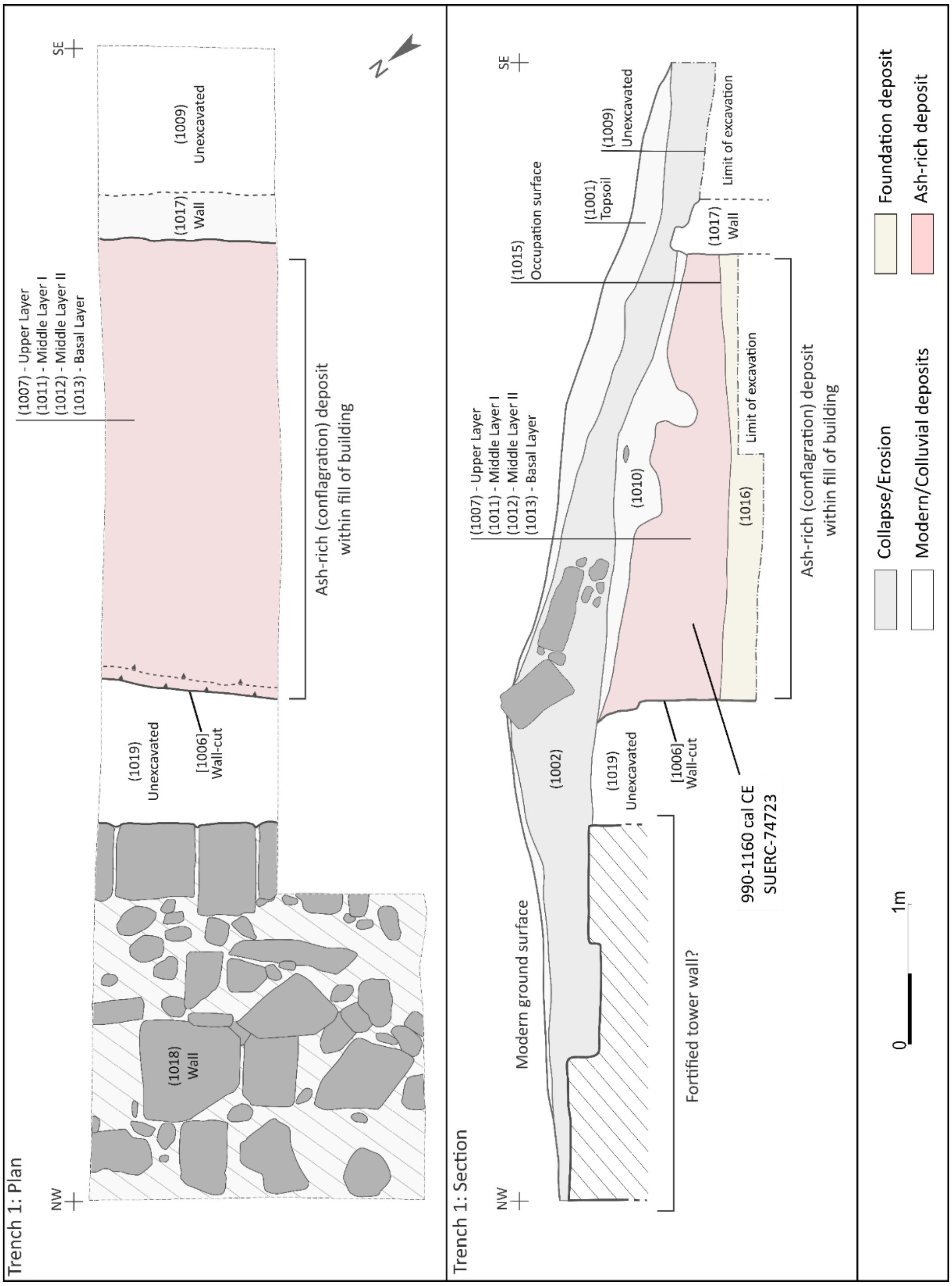


Figure 4.14: Plan and section of Trench 1, La Mora Encantada. Base of ash-rich deposit directly AMS ^{14}C dated to 990-1160 cal CE (SUERC-74723). Compare with Table 4.6. Illustration by the author, adapted from (Gerrard and Gutiérrez 2018b).

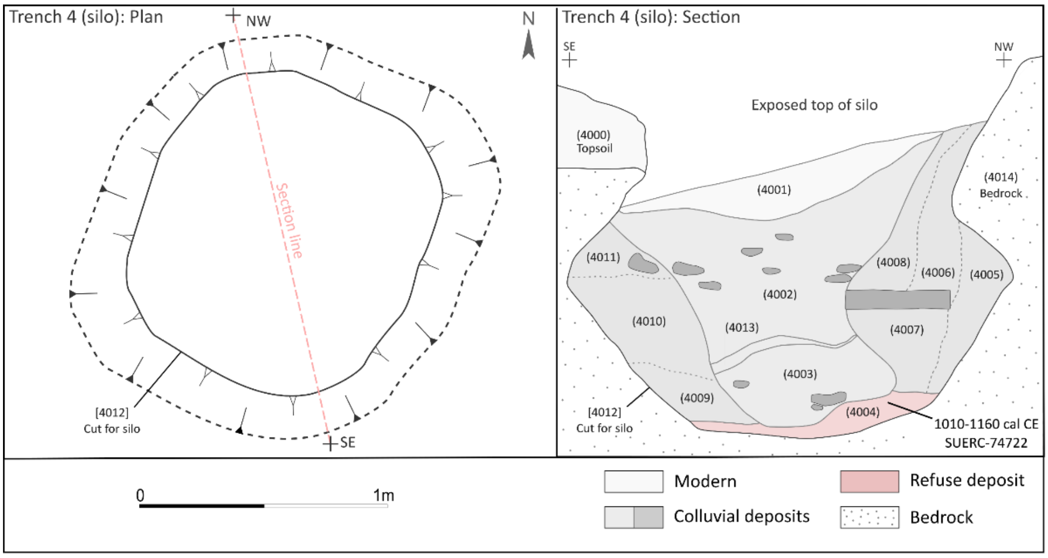


Figure 4.15: Plan and section of Trench/Silo 4, La Mora Encantada. Basal fill of silo directly AMS ^{14}C dated to 1010-1160 cal CE (SUERC-74722). Compare with Table 4.6. Illustration by the author, adapted from Gerrard and Gutiérrez (2018b).

Figure 4.16: Photograph of Trench/Silo 4, La Mora Encantada, during excavation. Photograph by the author.

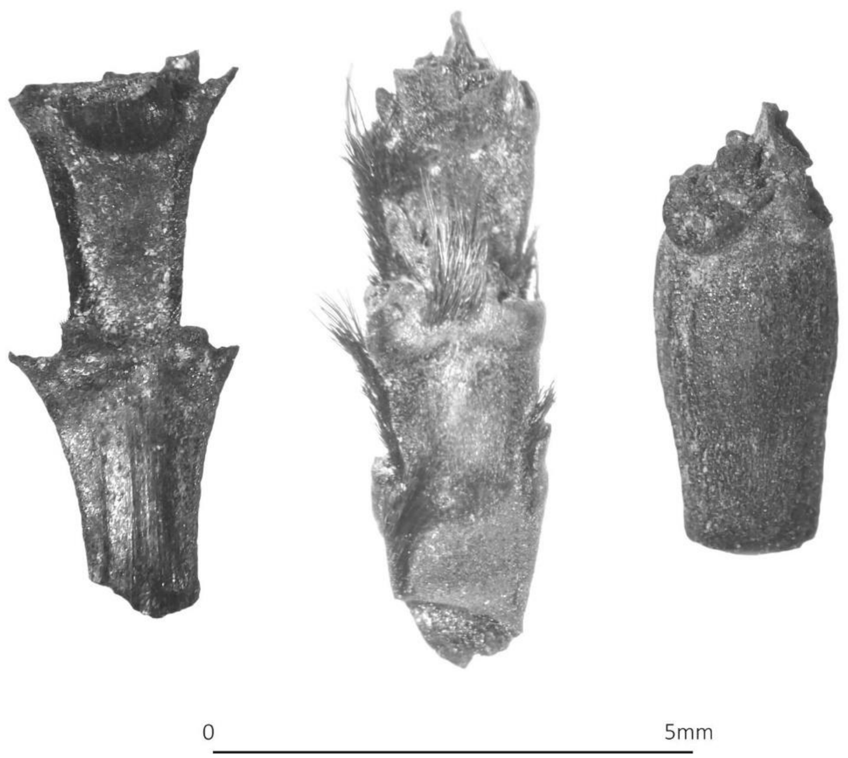


Figure 4.17: Rachis segments of 6-row hulled barley (left), durum wheat (centre) and bread wheat (right). All recovered from context (1013), sample 7. Photographs by the author.

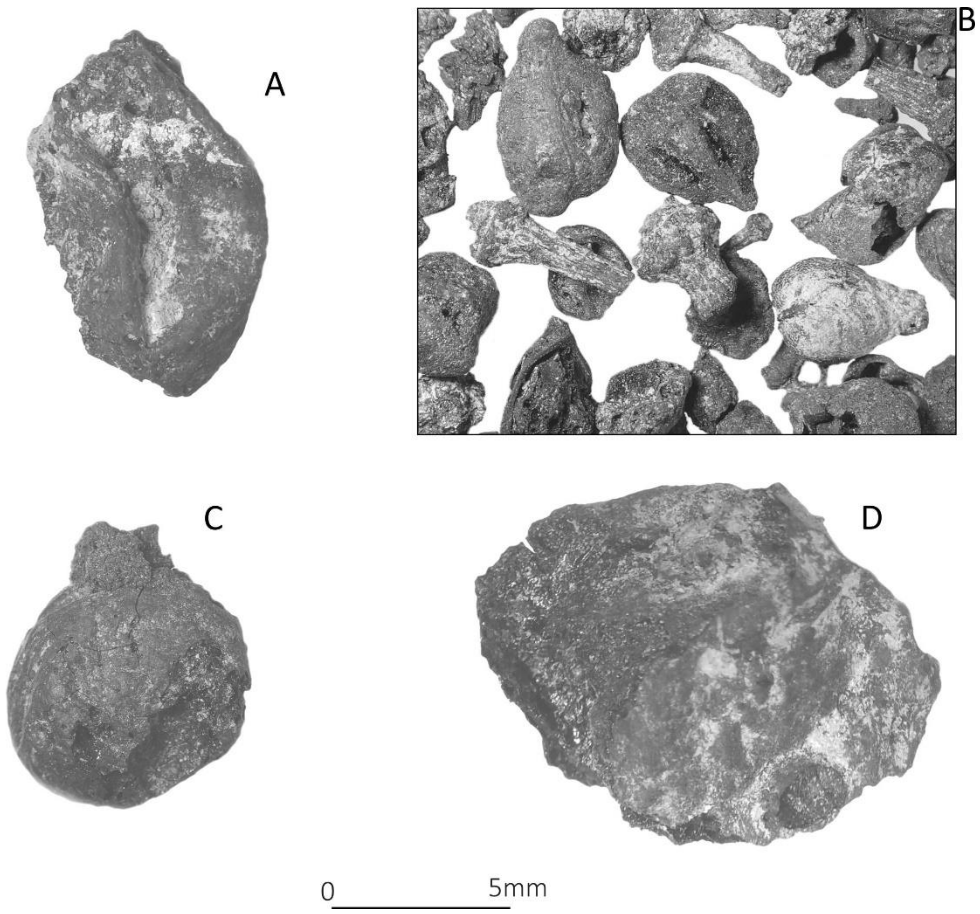


Figure 4.18: Probable grape-pressings. 'Pressed' grape skin (A), whole and fragmented seeds/pips and pedicles (B), immature whole grape (C), 'pressed' grape skin (D) All recovered from context (1013), sample 7. Photographs by the author.

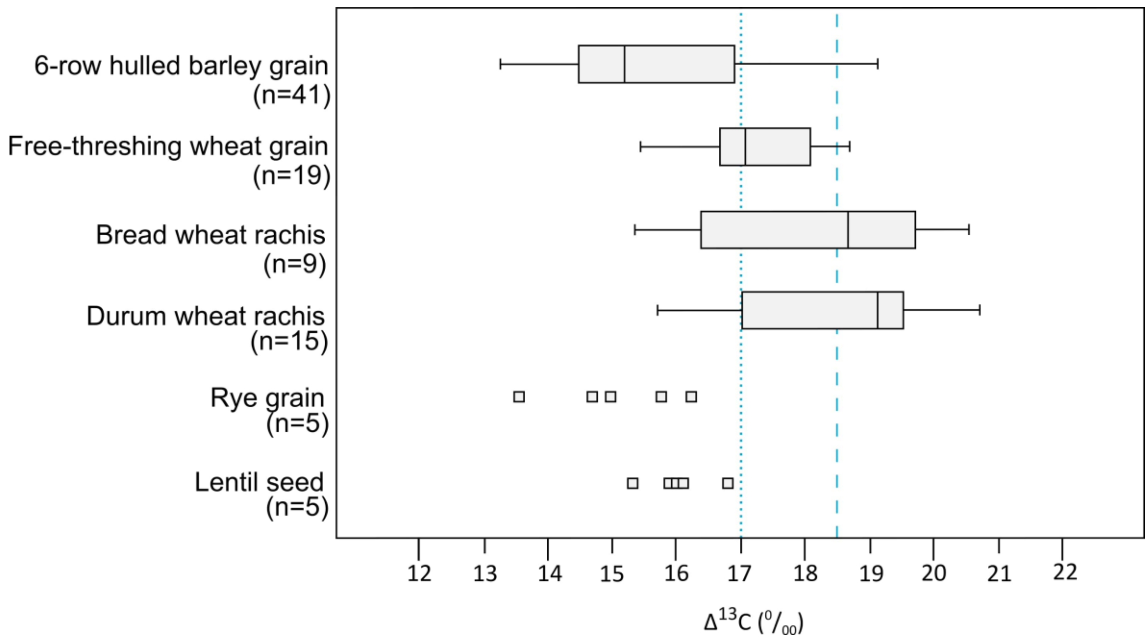


Figure 4.19: Stable isotope results, La Mora Encantada. Samples with >5 items are represented by box-plots. The whiskers reflect the minimum and maximum values, the grey reflects the interquartile range and the vertical black line reflects the median. The dashed vertical line reflects 'well-watered' (irrigated) hulled barley, the dotted vertical line reflects 'well-watered' (irrigated) free-threshing wheat and lentil (see Wallace et al. 2013, Figure 2.2 and Tables 2.5-2.6). For mean, minimum and maximum values see Table 4.10.

4.20: Aerial photograph showing the location of Iglesia de San Miguel de Ambel. The Casa Conventual de Ambel is also plotted for reference. (Google Earth 2019, base map).

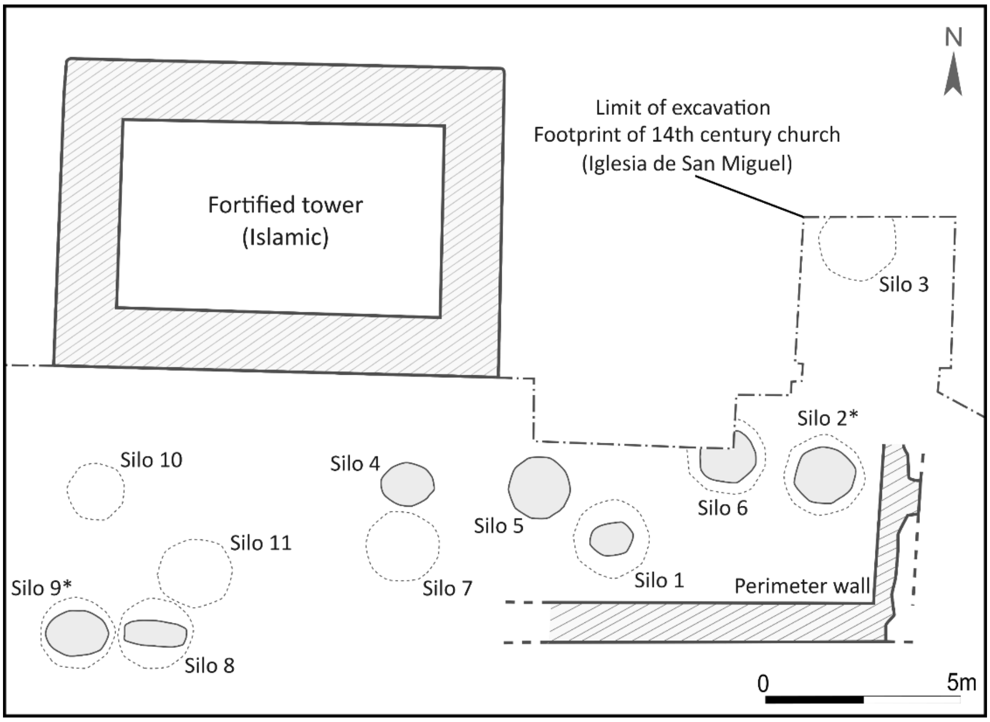


Figure 4.21: Simplified plan of trench excavated within Iglesia de San Miguel de Ambel. The two silos sampled are denoted by an '*'. Illustration by the author, adapted from Blanco Morte (2007).

Figure 4.22: Aerial photograph showing the location of Palacio de Bulbuente. The River Huecha is also plotted for reference. (Google Earth 2019, base map).

Figure 4.23: General photograph of the building complex, Palacio de Bulbuente. The samples were collected from excavations undertaken in the brick/tapial palace, adjoining the tower. Photo © C. Gerrard.

Figure 4.24: Photographs of mid-14th century conflagration/destruction deposit, Palacio de Bulbuente. A: General photo during excavation, with exposed burnt adobes on the left, the charred door frame in the centre and burnt roofing tile on the right. The deposit has been cut by a later storage container in the top right. B: Detail of the charred door frame; C: detail of burnt and smashed pottery vessel. Photographs by the author.

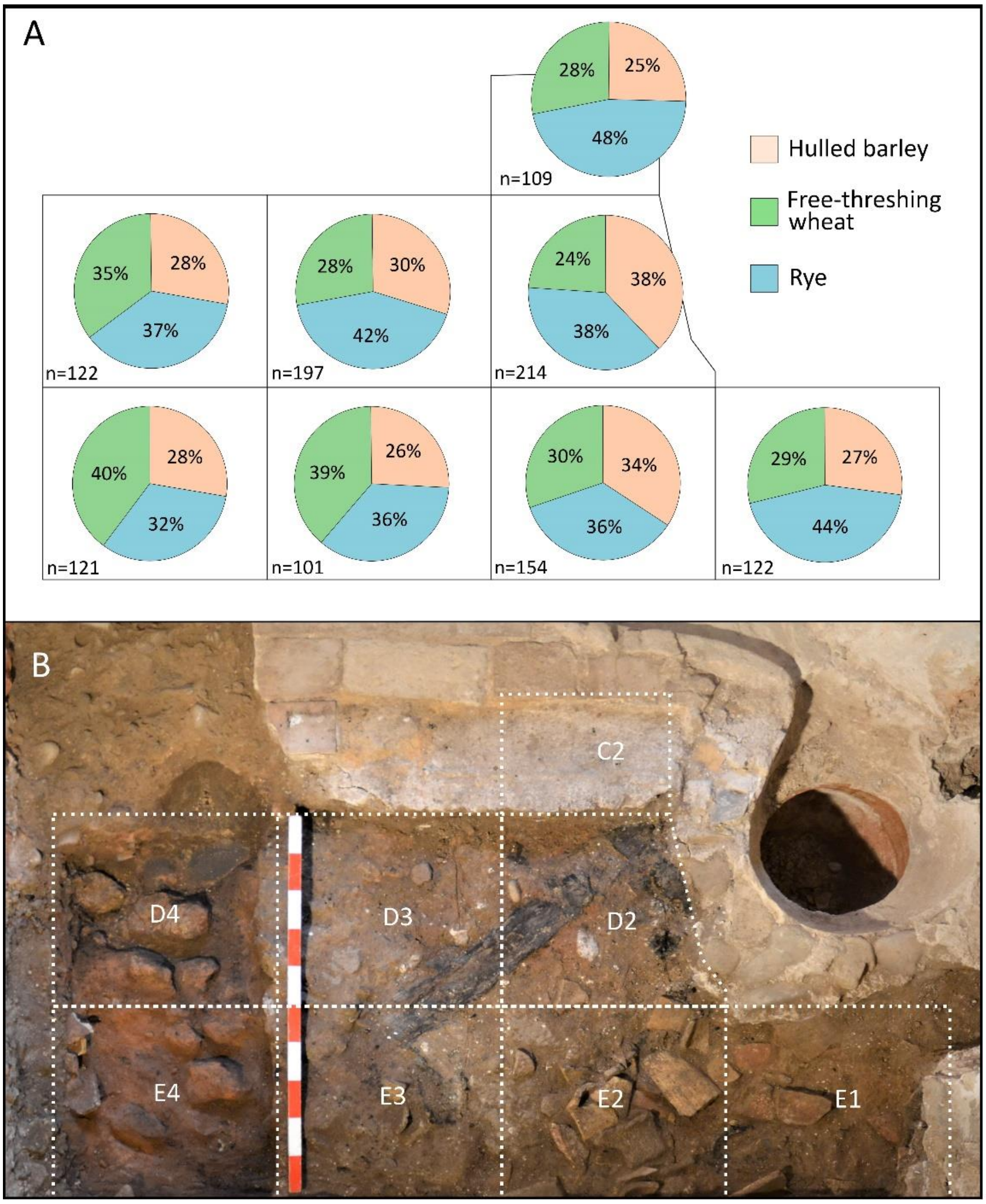


Figure 4.25: Pie charts displaying proportions of hulled barley, free-threshing wheat and rye displayed by grid. Note that samples from Trench B are not depicted, although the same pattern is repeated with similar proportions of all three crops. Grid C-2 has not yet been excavated in the photograph.

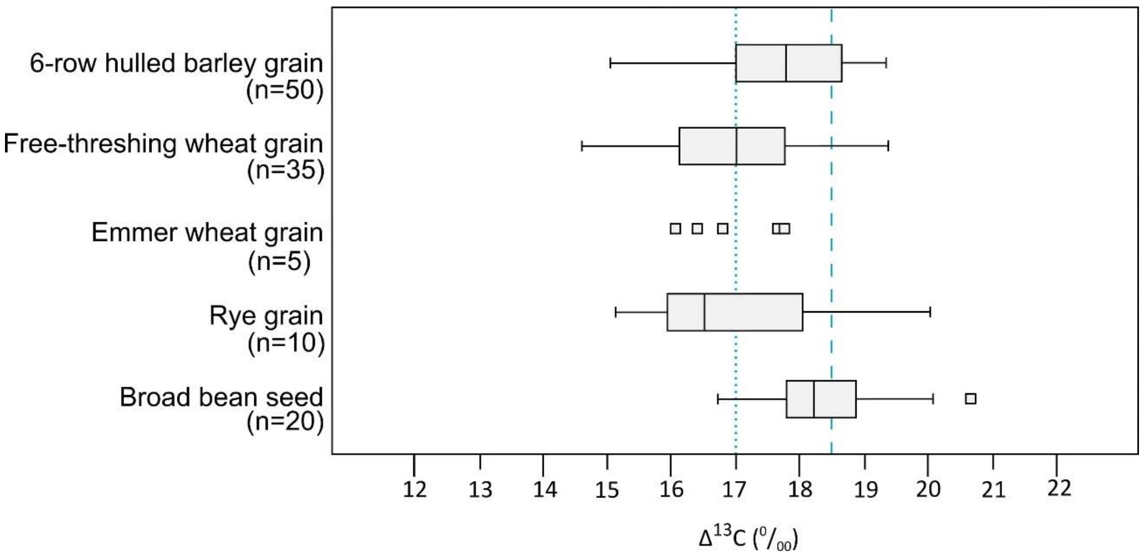


Figure 4.26: Stable isotope results, Palacio de Bulbuente. Samples with >5 items are represented by box-plots. The whiskers reflect the minimum and maximum values, the grey reflects the interquartile range and the vertical black line reflects the median. The dashed vertical line reflects ‘well-watered’ (irrigated) hulled barley, the dotted vertical line reflects ‘well-watered’ (irrigated) free-threshing wheat and lentil (see Wallace et al. 2013, Figure 2.2 and Tables 2.5-2.6). Mean, minimum and maximum values are presented in Table 4.17.

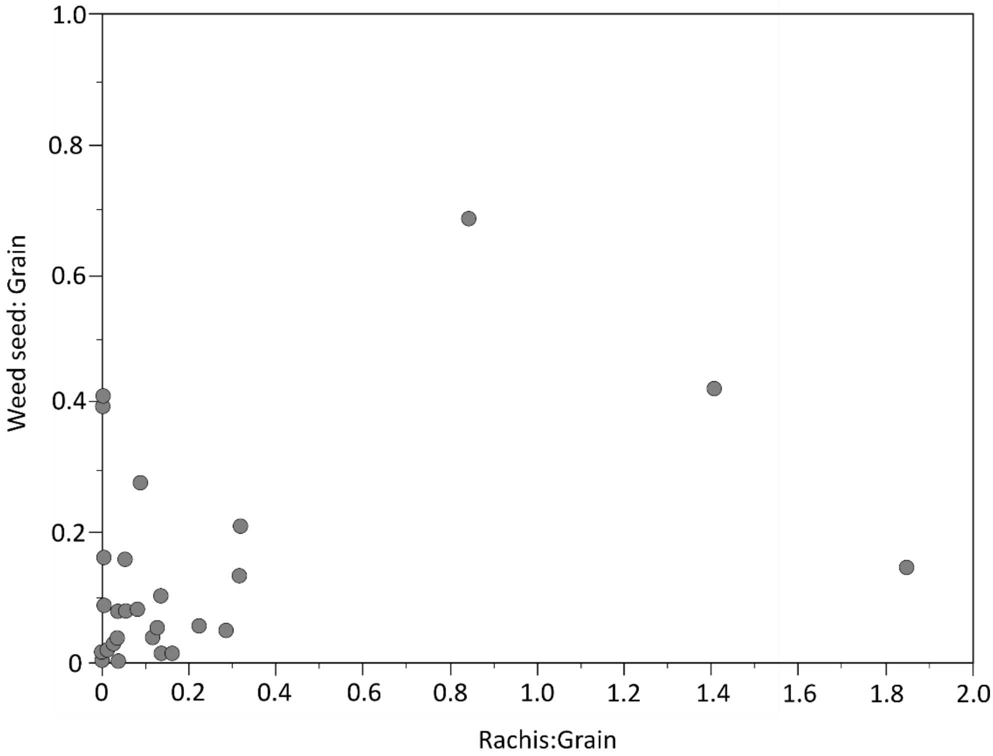


Figure 4.27: Ratios of weed seeds to grain, and rachis to grain, Palacio de Bulbuente. Ratios have only been calculated for samples containing >30 weed seeds/rachises/grains, calculated following van der Veen (2007). The clustering of samples in the bottom left reflect grain-rich samples, whilst the three samples separated on the right contain higher rations of rachises and/or weed seeds. Compare with Table 4.18 for crop-specific ratios which are presented per sample.

Figure 4.28: Aerial photograph showing the location of Castillo de Grisel. (Google Earth 2019, base map).

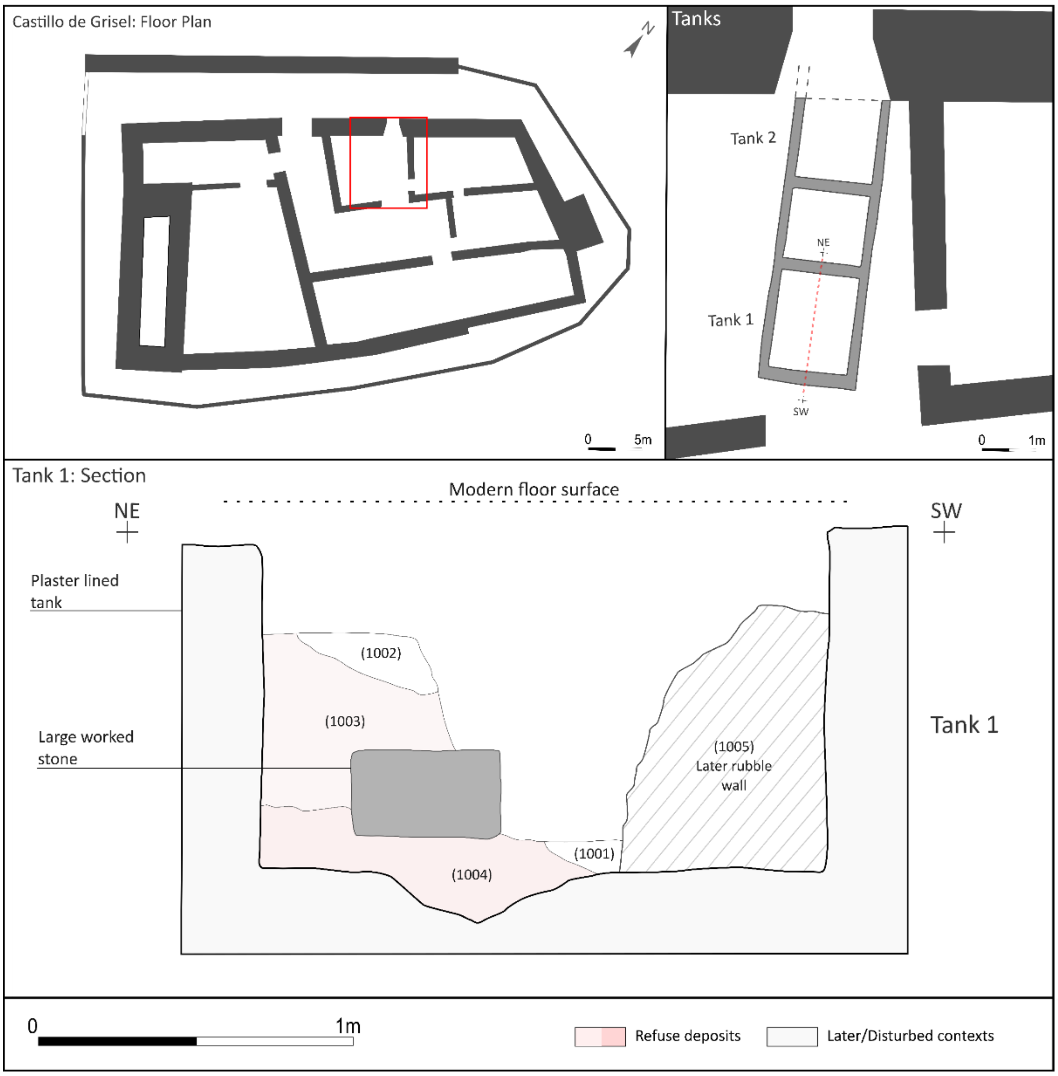


Figure 4.29: Site and trench plan of Castillo de Grisel. The bottom image is section through the fill of Tank 1. Illustration by the author.

Figure 4.30: Aerial photograph showing location of Casa Conventual de Ambel. The Iglesia de San Miguel de Ambel is also plotted for reference. (Google Earth 2019, base map).

	Roman	Early Medieval	Early Medieval
	Previous studies	Previous studies	This PhD
Cereals			
Oat	+	+	+?
Hulled Barley	+++	+++	+++
Naked Barley	+	+	-
Rye	+	++	+
Free-threshing Wheat	+++	+++	+++
Bread-type Wheat	+	-	++
Durum-type Wheat	+?	-	-
Emmer Wheat	+	+	+?
Millets			
Broomcorn Millet	+	+	+
Foxtail Millet	-	+	+
Oil/Fibre Crops			
Gold-of-pleasure	-	-	+
Flax	-	++	+?
Pulses			
Grass Pea/Red Pea	+	+	+
Lentil	++	+	+
Pea	++	+	-
Bitter Vetch	+	+	+
Broad Bean	+	+	-
Vetches	+	+	-
Fruits/Nuts			
Hackberry	-	+	-
Acorn	-	+	-
Hazelnut	++	+	+
Melon	-	+?	-
Fig	+++	+++	+++
Walnut	+	+	-
Apple/Pear	+	-	-
Mulberry	-	+	+
Olive	++	+	+
Almond	+	+	-
Sweet Cherry	++	+	+
Sour/Sweet Cherry	++	+	+
Plum	++	+	
Peach	++	-	+
Sloe	+	+	-
Pomegranate	+?	-	-
Blackberries	+	+	-
Grape	+++	+++	+++
Stone Pine	++	-	-
Herbs, Spices and Other			
Coriander	-	-	+

Table 5.1: Comparison between archaeobotanical evidence analysed in this PhD and previous archaeobotanical studies in the north-east (Roman and early medieval). See Appendices 13 and 14 for the full dataset.? = (cf.) identification; + = rare; ++ = occasional; +++ = common.

Crop	Barbastro	Barcelona	Calatayud	Daroca	Fraga	Huesca	Lérida	Monzón	Ricla	Tarragona	Tortosa	Tudela	Zaragoza
Cereals													
Wheat	-	X	-	-	-	-	-	X	-	-	-	X	X
Oil/Fibre Crops													
Flax	-	-	-	-	-	-	X	-	-	-	-	-	-
Fruits/nuts													
'Fruit'	X	-	X	-	X	-	X	X	-	X	-	X	X
Apple	-	-	-	-	-	X	-	-	-	-	-	-	X
Cherry	-	-	-	-	-	-	-	-	-	-	-	-	X
Fig	-	-	-	-	-	-	-	-	-	-	-	-	X
Grape	X	-	X	X	X	-	-	-	-	-	-	-	X
Hazelnut	-	-	-	-	-	-	-	-	-	X	-	-	-
Medlar*	-	-	-	-	-	X	-	-	-	-	-	-	-
Olive	-	-	-	-	X	-		-	-	-	-	-	-
Peach	-	-	-	-	-	-	-	-	-	-	-	-	X
Pear	-	-	-	-	-	X	-	-	X	-	-	-	X
Pistachio	-	-	-	-	-	-	-	-	-	X	-	-	-
Service*	-	-	-	-	-	X	-	-	-	-	-	-	-
Sweet chestnut*	-	-	-	-	-	-	-	-	-	X	-	-	-
Walnut	-	-	-	-	-	-	-	-	-	X	-	-	-
Other													
Saffron*	-	-	-	-	X	-	-	-	-	-	X	-	-

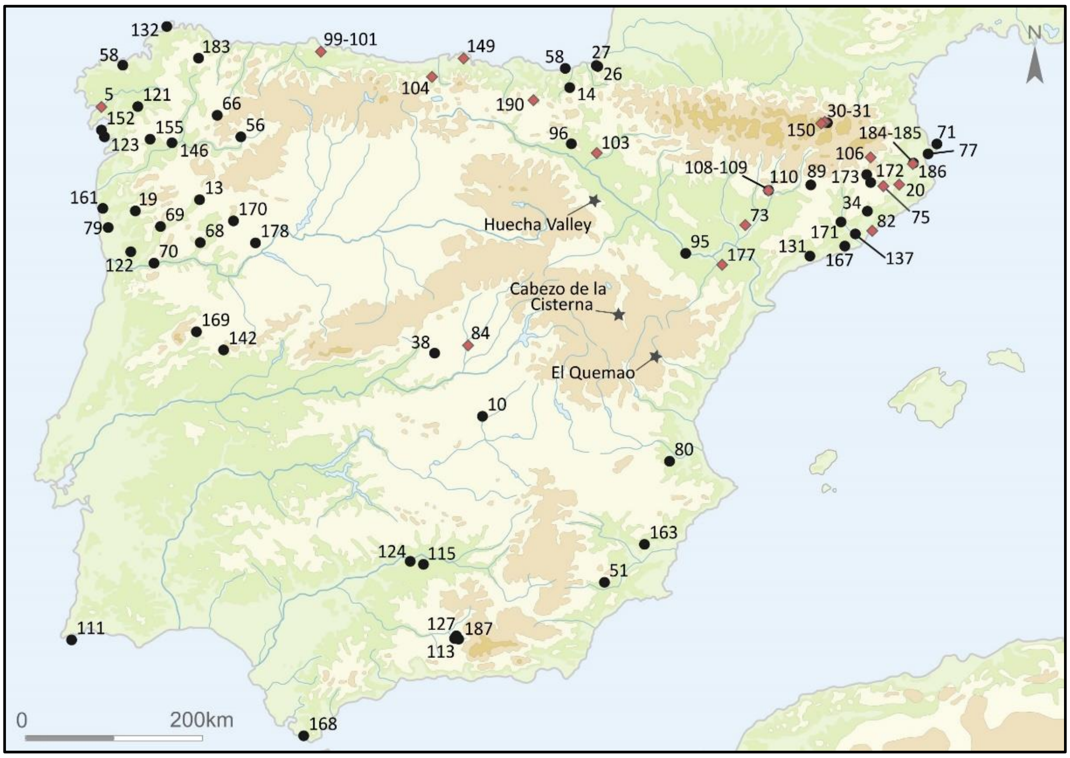
Table 5.2: Crops recorded in documentary sources for the Islamic period in the north-east. Compiled using data from Ortega Ortega (2010), Bramon (2000), Martin Duque (1957) and Cuchí Oterino (2005). Crops denoted with an '*' have not been recorded in the archaeobotanical record.

	Islamic Previous studies	Islamic This PhD
Cereals		
Oat	+?	+?
Hulled Barley	+++	+++
Naked Barley	-	+?
Rye	+	++
Free-threshing Wheat	+++	+++
Bread-type Wheat	+	+++
Durum-type Wheat	-	+++
Emmer Wheat	+	-
Einkorn Wheat		+
Millets		
Broomcorn Millet	-	++
Foxtail Millet	+	+
Oil/Fibre Crops		
Gold-of-pleasure	+	-
Flax	+	++
Pulses		
Grass Pea/Red Pea	-	+
Lentil	+	+
Pea	-	+
Bitter Vetch	+	+
Fruits/Nuts		
Hackberry	-	+
Carob	+	-
Melon/Cucumber	++	-
Fig	+++	+++
Walnut	+	+++
Apple	+	-
Apple/Pear	+	-
Mulberry	-	++
Olive	+	+
Almond	+	-
Sweet Cherry	-	+
Sour/Sweet Cherry	-	+
Peach	+	-
Pomegranate	+	-
Blackberries	+	++
Grape	+++	+++
Stone Pine	+	-
Herbs, Spices and Other		
Celery	+	-
Fennel	+	-
Garlic	-	+
Nigella	+	-

Table 5.3: Comparison between archaeobotanical evidence analysed in this PhD and previous archaeobotanical studies in the north-east (Islamic). See Appendices 13 and 14 for the full dataset.? = (cf.) identification; + = rare; ++ = occasional; +++ = common.

Cereals	Later medieval Previous studies	Later medieval This PhD
Oat	+	++
Hulled Barley	+++	+++
Naked Barley	+	+?
Rye	++	+++
Free-threshing Wheat	+++	+++
Bread-type Wheat	+?	+
Durum-type Wheat	+?	+
Emmer Wheat	++	+
Einkorn Wheat	+	+?
Millets		
Broomcorn Millet	+	++
Foxtail Millet	+	+
Sorghum	+	-
Oil/Fibre Crops		
Gold-of-pleasure	-	-
Flax	+	+
Pulses		
Chickpea	+	-
Lentil	+	+
Pea	+	+
Bitter Vetch	+	+
Broad Bean	+	++
Vetches	+	-
Fruits/Nuts		
Hackberry	+	-
Acorn	+	-
Carob	+	-
Hazelnut	-	+
Melon	+	-
Fig	+++	++
Walnut	+	+++
Apple/Pear	+	-
Mulberry	-	+
Olive	+	+
Almond	+	+
Sweet Cherry	-	+
Sour/Sweet Cherry	+	+
Plum	+	+?
Peach	+	+
Blackberries	+	+
Grape	+++	+++

Table 5.4: Comparison between archaeobotanical evidence analysed in this PhD and previous archaeobotanical studies in the north-east (later medieval). See Appendices 13 and 14 for the full dataset.? = (cf.) identification; + = rare; ++ = occasional; +++ = common.



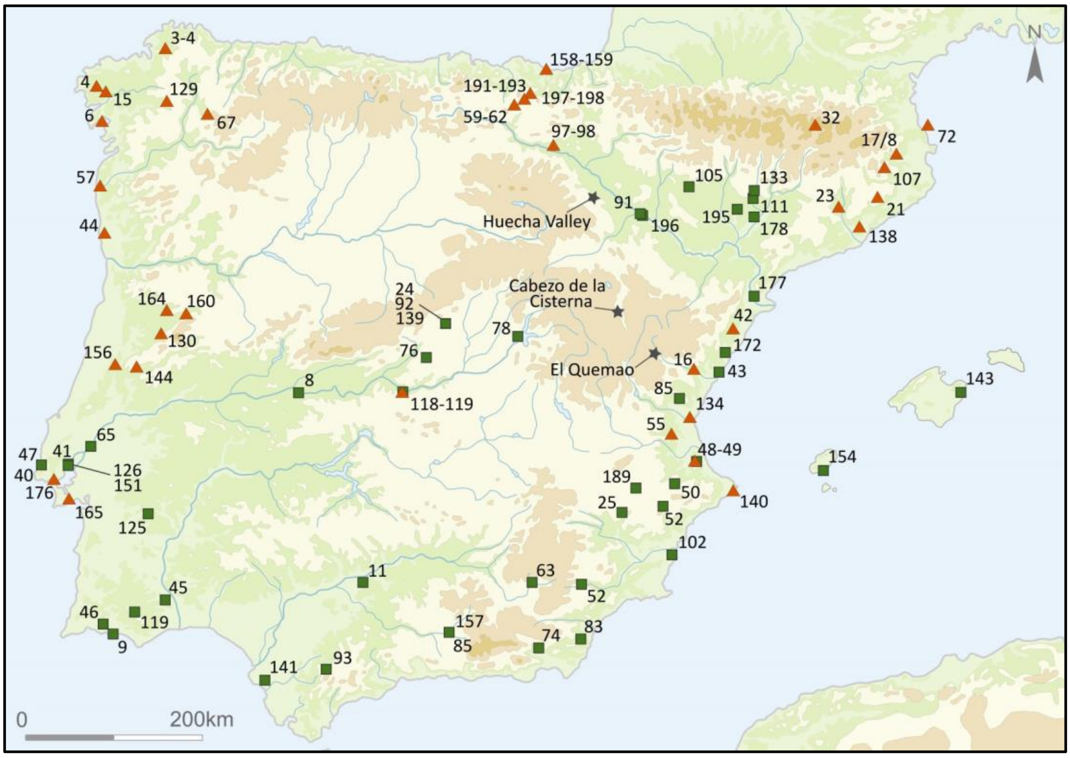


Figure 5.1: Maps showing the location of previous archaeobotanical studies undertaken in the Iberian Peninsula. Top: Roman sites (black circles), early medieval sites (red diamonds). Bottom: Islamic sites (green squares), later medieval/medieval Christian sites (orange triangles). See Appendix 13 for information on the sites, and Appendix 14 for the archaeobotanical data. The location of the study areas analysed for this PhD are also plotted as stars.

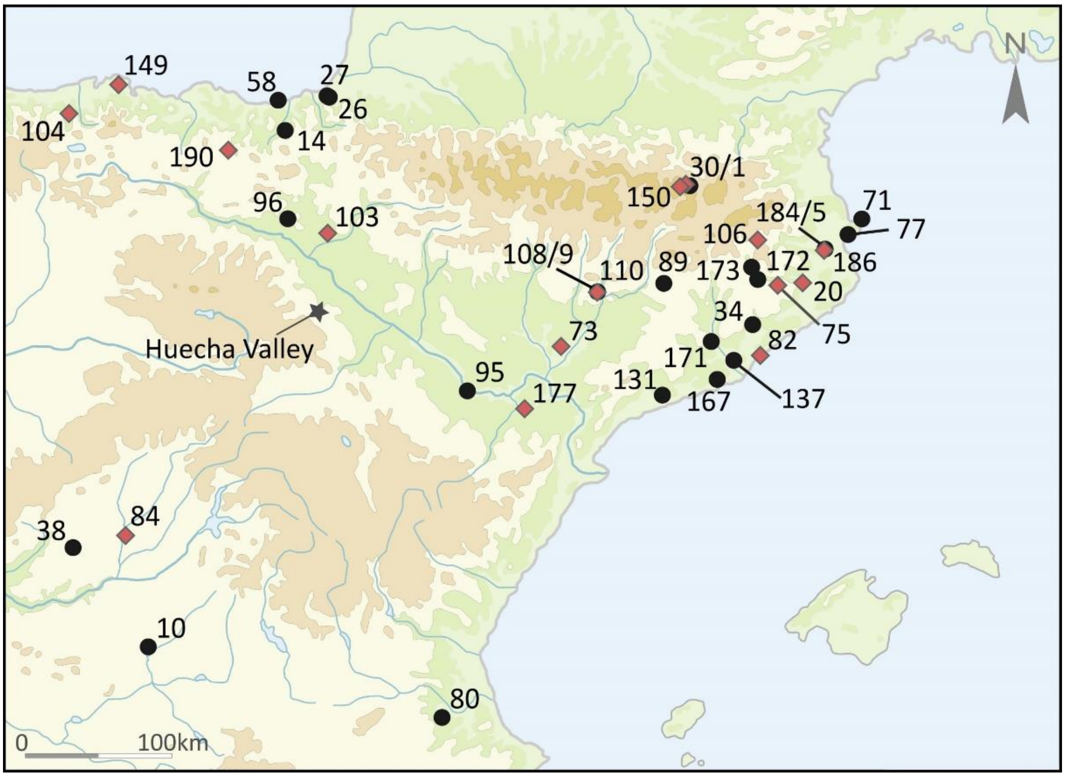


Figure 5.2: Maps showing the location of previous archaeobotanical studies undertaken in the north-east of the Iberian Peninsula on Roman sites (black circles) and early medieval sites (red diamonds). See Appendix 13 for information on the sites, and Appendix 14 for the archaeobotanical data. The location of the early medieval archaeobotanical evidence analysed for this PhD in the Huecha Valley is also plotted as a star.

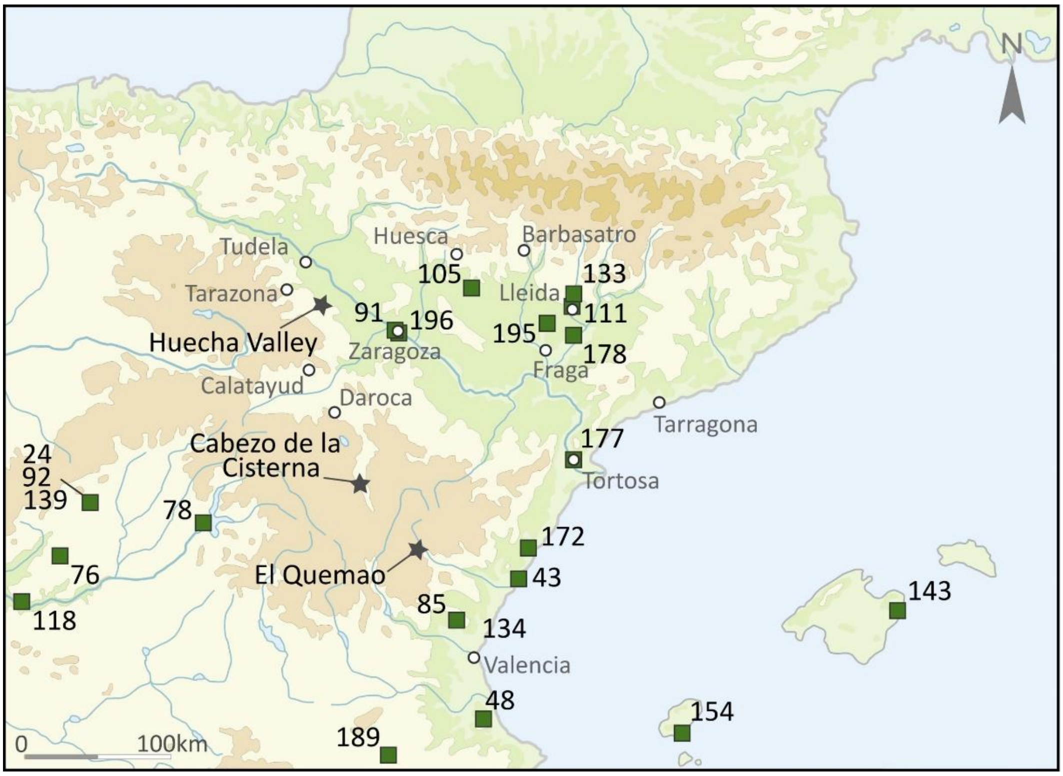


Figure 5.3: Maps showing the location of previous archaeobotanical studies undertaken in the north-east of the Iberian Peninsula on Islamic sites (green squares). Locations of areas referred to the text are also indicated. See Appendix 13 for information on the sites, and Appendix 14 for the archaeobotanical data. The location of the Islamic archaeobotanical evidence analysed for this PhD in the Huecha Valley, Cabezo de la Cisterna and at El Quemao are also plotted as stars.

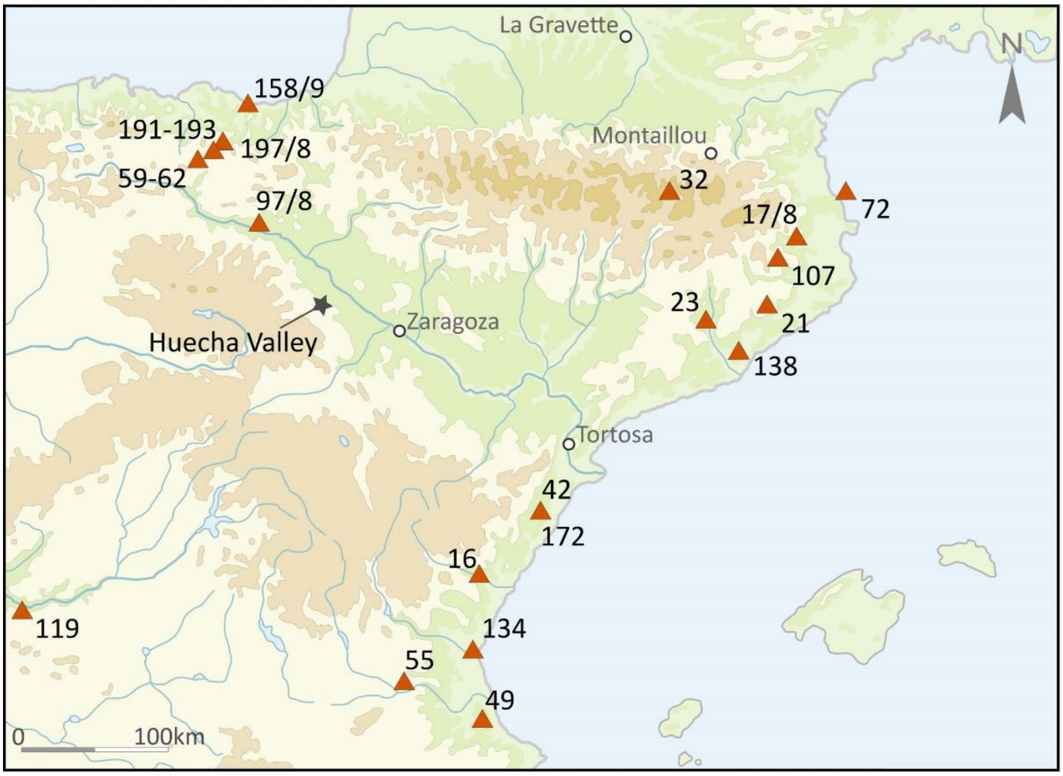


Figure 5.4: Maps showing the location of previous archaeobotanical studies undertaken in the north-east of the Iberian Peninsula on later medieval/medieval Christian sites (orange diamonds). Locations of areas referred to the text are also indicated. See Appendix 13 for information on the sites, and Appendix 14 for the archaeobotanical data. The location of the later medieval archaeobotanical evidence analysed for this PhD in the Huecha Valley is also plotted as a star.