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Investigating early agriculture, plant use and culinary practices at Neolithic Jarmo (Iraqi Kurdistan)

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ABSTRACT

The site of Jarmo in Iraqi Kurdistan has yielded key archaeological evidence which supports its interpretation as a large PPNB village. As such, it is the perfect candidate for the study of early agriculture, plant uses, food preparation and cooking practices. In order to explore these, new excavations and intensive sampling and flotation for the recovery of archaeobotanical remains were carried out in 2012 and 2014. This study presents the results from the analysis of the newly recovered archaeobotanical assemblage from Jarmo which has provided invaluable information about early crop agriculture and plant use. Furthermore, the in-depth study of recovered remains of archaeological food by high-resolution microscopy has shed light on culinary traditions and dietary choices during the Neolithic in the Central Zagros Area.

1. Introduction

For many archaeologists, the site of Jarmo in Iraqi Kurdistan is synonymous with the study of early agriculture and with multidisciplinary archaeology. This is due to previous excavations directed by Robert Braidwood (University Chicago) in 1948, 1950–51 and 1954–55 (Braidwood (1960); L. Braidwood et al 1983). Within the Braidwoods' hypothesis, Jarmo became representative of the earliest agricultural villages associated with the "hilly flanks of the [Fertile] Crescent", a phrase first used by Robert Braidwood (1948). The research led by Robert and Linda Braidwood was the first archaeological project that set out to explicitly document the transition from mobile foraging to settled agriculture in the Near East through a problem-oriented multidisciplinary project (see Watson 2003; 2004). It inspired many aspects in the development of agricultural origins research in Western Asia, including early archaeobotanical and zooarchaeological studies (Helbaek 1960). Nevertheless, those previous excavations and associated research took place prior to major methodological advances in both archaeological field sampling and in post-excavation laboratory analyses of plant and animal remains (Braidwood et al. 1983), as well as studies of lithic debitage and high-precision radiometric dating. It remains the case that little is known of the subsistence at Jarmo, and the limited evidence that was collected in the 1950's is not readily comparable to data currently available from regions to the west, including the Levant and Anatolia (e.g. Asouti and Fuller 2013; Arranz-Otaegui et al. 2016), where many excavations have taken advantage of improved methodologies with systematic sampling programs in more recent years. Thus, new research offers an opportunity to better understand this site and make new contributions to its place in the wider development of early village farming in the region. With this aim, new targeted excavations were carried out in 2012 and 2014, with a focus on extensive environmental sampling and flotation. These methods facilitated the systematic recovery of archaeobotanical remains, marking the first time such data became available from this site. Analysis of the recovered plant assemblage highlights the importance of cereals and pulses as staple crops and their use for the preparation of a range of food products.

Jarmo also provides the perfect setting to investigate food practices and cooking techniques in a comprehensive way, combining archaeological field data with the analysis of preserved remains of food. A range of food preparation and cooking installations were identified as part of the domestic arrangement of the houses and spaces at Jarmo (Braidwood (1960)). These include fire installations (e.g. hearths and ovens), food processing tools (e.g. groundstones) and cooking containers (e.g. stone and pottery vessels). In regard to pre-cooking food processing,

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numerous fragmentary querns, in their majority made of limestone and chert, were found in the buildings and courtyards from Jarmo. These have been interpreted as "fixed-in place" stones which were most likely involved in the processing of plant foods such as cereals and other crops through grinding (Moholy-Nagy 1983). In addition, many portable limestone grinding slabs have been recovered from Jarmo and have been interpreted as tools for crushing pigments and other materials such as plant foods (nuts, spices, etc) (Moholy-Nagy 1983).

During Braidwood's excavations, a variety of features were interpreted as fire installations and more specifically as "oven-like" features or "baked-in place-basins". During new excavations in 2014 (the UCL season) and consequent post-excavation analysis, these features were found to represent possible pit ovens, hearths and ovens, similar to those recovered from other Neolithic 'megasites' in Southwest Asia. Braidwood et al. (1983) indicates the presence of these types of structures inside the domestic architectural spaces (houses) and distinguishes between two types. Earlier, a type of fire installation which appears in the early levels from Jarmo, described as "baked-in-place basins", which were found to resembled roasting-pit ovens which had been lined with burnished clay or a flat stone and often filled with ash, charcoal and stones. These can also be described as rimmed hearths, having raised baked clay walls that retain some of the heat of the fire. Similar features are known from earlier sites such as Jerf el Ahmar and Mureybet in Syria (Cauvin 2000; Molist 1988; Stordeur and Ibáñez (2008)). These were subsequently slowly replaced by "oven-like features" with a dome in the later levels, which would correspond to domed ovens (or *tabun/firin*) made of clay or *tauf* materials. Although Braidwood initially suggested the role of the "oven-like" features was for bread baking, as a consequence of the presence of both crops and wild seeds in the archaeobotanical record, Braidwood (1960) suggested an alternative use of these installations for dehusking of glume wheat and hulled barley species, similarly to the European "corn-dryers" (Braidwood et al. 1983, 158). However, archaeological excavation across the northern Fertile Crescent and Anatolia provide recurrent evidence that domed ovens, inferred to be involved with cooking and bread baking appeared from ca. 7500 BCE (Fuller and González Carretero 2018), whereas corn drying ovens are better known from northern Europe (a damper climate) in the Iron Age or Roman periods (Monk and Kelleher 2005).

Before the appearance of pottery at the site, stone vessels were the main cooking utensil. A total of 1323 stone vessels were recovered from Braidwood's first two excavation seasons showing impressive aesthetic finish with polished thin walls. Adams (1983) studied the materials used for the fabrication of these and concluded that the preferred materials were marble, limestone and less often sandstone, some of them of aesthetically pleasing mottled type or varieties with red or grey veins. Many different types of vessels were distinguished among the recovered assemblage, including saucers/plates, cups and bowls with rounded or flat bases, with flaring or vertically rounded sides. The variety of forms among the stone vessels seems to decline throughout the sequence in combination with a decrease in the use of large stone vessels. This has been interpreted as perhaps a consequence of the emergence of production of pottery vessels and therefore a widening of types of cooking or storage implements available (Adams (1983)).

Pottery emergence at Jarmo is late in the sequence of occupation, with the highest concentration of pottery sherds recovered from the latest two levels of Braidwood's excavations. From Braidwood's level 4 downwards there is no evidence of ceramics in the Central Buildings part of the site (Braidwood Trench J.II, southeastern part) while a large amount of pottery sherds (>1000) were recovered from the top two levels (levels 1 and 2) and surface deposits (Adams (1983)). All the examples of pottery recovered from Jarmo were handmade and primarily tempered with chaff and straw. Although there are some similarities between the forms in which stone and pottery vessels were made, in general, pottery vessels were more associated with the use of large pots and bowls, while the most commonly recovered stone vessels represent small forms such as plates, cups and small serving bowls. This, together with the decrease in the production of stone vessels, could have been due to a specialisation of each type of fabric for different uses (Adams (1983)), with ceramics perhaps more associated with cooking activities.

While Jarmo is no longer seen as one of the earliest sites relating to the beginnings of domestication it represents an important site in terms of the development of agricultural settlements during the PPNB. Further, it was hoped to obtain new material for radiocarbon dating, on crops and most importantly whether charred remains pertaining to burnt food were present that might help elucidate culinary practices on the site.

2. Excavations and chronology

Jarmo is located in a valley on the foothills of the Zagros Mountains in the Chamchamal Plain in the Sulaimaniyah Province in Iraqi Kurdistan (35°33′20.87″N, 44°55′49.05″E). The site was established in the proximity of the Basian Pass and lies on a natural promontory above the Cham-Gawra wadi, at an altitude of 800 m above sea-level (Fig. 1). Jarmo is an example of the Neolithic 'megasites' which emerged during the Pre-Pottery Neolithic B (hereafter PPNB) in Western Asia. The site was first excavated by Robert and Linda Braidwood and their team from the Oriental Institute at the University of Chicago in the 1950's during three fieldwork seasons (1947–48, 1950–51 and 1954–55; Braidwood et al. 1983). Later excavations and study seasons continued into the early 1960's, when most of the post-excavation specialist work was carried out, including archaeobotanical analysis.

Previously, the site was thought to extend up to as much as 5 ha (Braidwood et al. 1983) and to have had a long and continuous occupation, spanning over more than 1500 years from ca.7300 to 5800 BCE, covering the Pre-Pottery Neolithic to the Late Neolithic (ceramic) levels. However, these dates were left uncalibrated (see Braidwood et al. (1983), note 1). As a result of the excavations by Braidwood in the 1950's, 9 building (occupation) levels were identified. In summary, Levels 1 and 2 were associated with a potsherds' midden and preserved stone wall foundations. From Level 4 downwards there is no evidence of ceramics, while a small number (32 sherds) of pottery remains were reported stratified from Level 3 (Adams (1983)). In the Central Buildings area of the site (Braidwood Trench J.II) a large amount of pottery sherds (>1000) were recovered from the top two levels (Levels 1 and 2) and surface deposits. Thus, Levels 1 and 2 are believed to represent a true Pottery Neolithic, in both trenches J.I and J.II. Jarmo has yielded almost no secure C14 dates, largely due to a variety of complications regarding the early state of radiocarbon dating technology at the time of the Braidwood excavations, the nature of the samples (Kozlowski (1994)), and the poor carbon preservation of the material, leading to very large radiocarbon errors (Braidwood 1983). As such the site is poorly dated, and prior to the work presented here yielded only two reliable dates with error margins of less than 120 years. The older date comes from a pig bone and relates to the pre-ceramic occupation, level 6, locus MQ1519 with a calibrated date of 7470–7070 cal. BC (2-sigma; NOSAMS-no code, 8240 ± 65 BP) (Price and Arbuckle 2015). The later date comes from chaff-tempered pottery recovered from trench J-II and provides a calibrated date of 6650–6390 cal. BC (GrN-6353, 7655 ± 75 BP) (Braidwood et al. (1983)). Further dates on charcoal from J-I might suggest occupation stretching as late as the early 6th millennium BC, but the reliability of these dates, which were analysed in the 1950's, is less certain. Our own assessment suggests the site was abandoned around 6200–6000 BCE (see below).

New excavations by the UCL Project began in 2012 and continued in 2014, with the aim of re-evaluating the Jarmo sequence established by Braidwood, and the assignment of Jarmo as one of the Neolithic sites with the earliest evidence of plant and animal domestication in Western Asia. As part of this new project, in 2012 two 1x1m test pits were excavated next to, and on top of, Braidwood's partially excavated J-II trench. In 2014 three additional trenches were opened with the aim of reproducing the Braidwood sequence and exposing the following

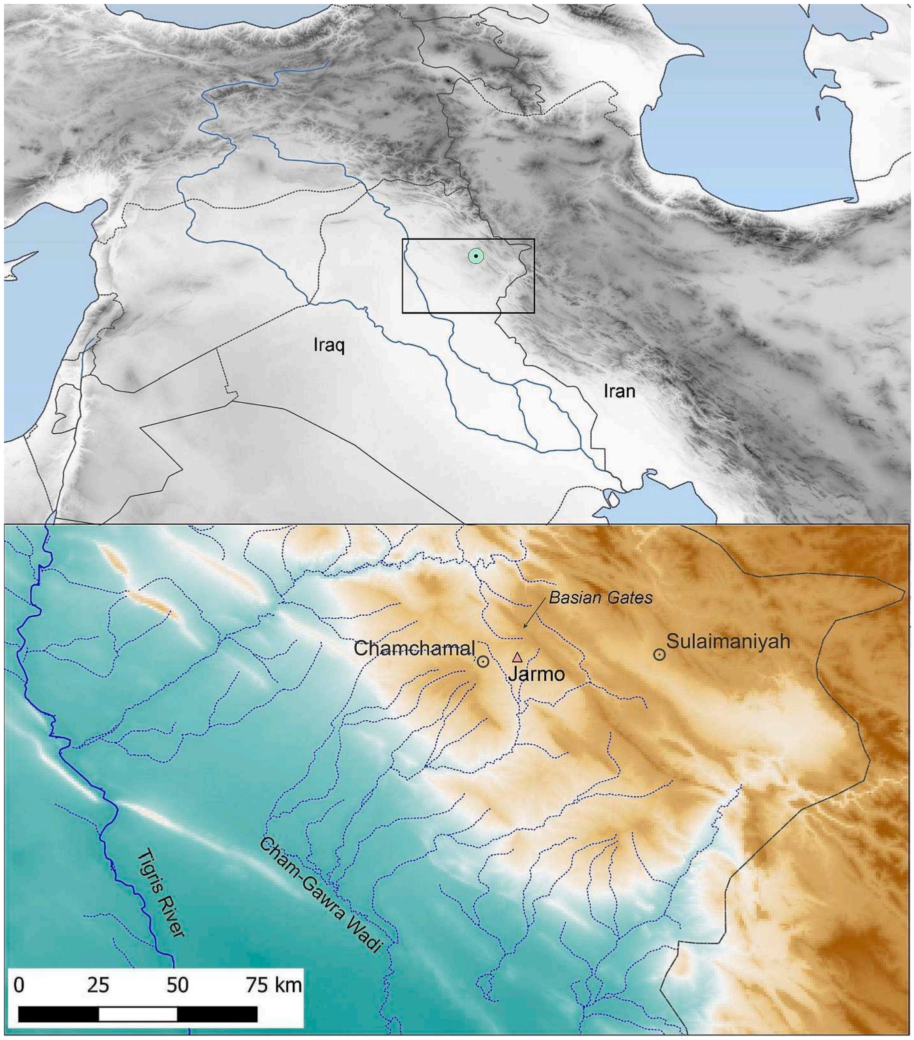

Fig. 1. Regional map of Jarmo in relation to modern Iraq.

occupation levels: Jarmo West (JW), adjacent to Braidwood's J-I bottom); Jarmo Central Buildings (JCB) on top of J-II; and Jarmo Central Midden (JCM), lying between J-II and J-III (Fig. 2). In addition, the project enabled extensive sampling and systematic recovery of plant and animal remains by bucket flotation, in 2012, and machine flotation and dry sieving, in 2014.

3. Materials and methods

New excavations prioritised the maximum recovery of charred macrobotanical remains. The primary strategy to achieve this was through excavation of small-scale trenches adjacent to the Braidwood excavation areas, from which systematic fine-scale sampling for the recovery of archaeobotanical, zooarchaeological, and micro-archaeological evidence was conducted (Fig. 3). More specifically, this involved excavation and recording through a single context system, in contrast to the Braidwood's building level system. All secure archaeological contexts were sampled for large-scale machine flotation following standardised methods. The chosen sieve size of 250 μm was used to maximise the potential recovery of a diverse range of charred plant macro-remains. Furthermore, wet-sieving of the heavy fraction on 2 mm mesh was also conducted to recover microfauna and small artefacts (e.g. lithic debitage, small beads). Additional sediment not taken for flotation was dry-screened on site through 3 mm sieves to aid in the full recovery of artefacts and bones (Fig. 3).

3.1. Macrobotanical analysis

An estimated total of 4463 L of soil were processed by both bucket (in 2012) and machine flotation (in 2014). A total of 83 flotation samples were collected using a 250-μm mesh and dried in the shade away from direct sunlight. All residues and flots from Jarmo underwent full analysis with macrobotanical remains sorted under a Leica S6D stereoscope at x0.63 to x50 and identified to species level when possible. The total number of plant remains recovered from the flots (i.e. seeds, nuts, fruits and chaff) were identified using modern seed reference collections located at the UCL Institute of Archaeology. Criteria for the differentiation of botanical families, genera and species were based on seed atlases (Anderberg 1994; Beijerinck 1947; Berggren 1969; 1981), archaeobotanical publications (e.g. Jacomet et al. 1989; Jones et al. 2000; Körber-Grohne 1991; Kohler-Schneider (2001)) and personal observations in comparison to reference collections at UCL (which are rich in taxa collected in Turkey and Syria). Once identified to the genus level, lists of geographically relevant species were extracted from *Flora of Iraq* and *Flora of Turkey*.

The macrobotanical remains were quantified following previously published, standard procedures. The 'minimum number of individuals' principle (Jones 1991) was used to depict a complete picture of the composition of the macrobotanical assemblage. Fragmented cereal kernels were common in the assemblage resulting in estimates of the number of whole items from fragments. Wood charcoal, tuber and dung fragments sorted from the > 2 mm size fractions of flot and heavy

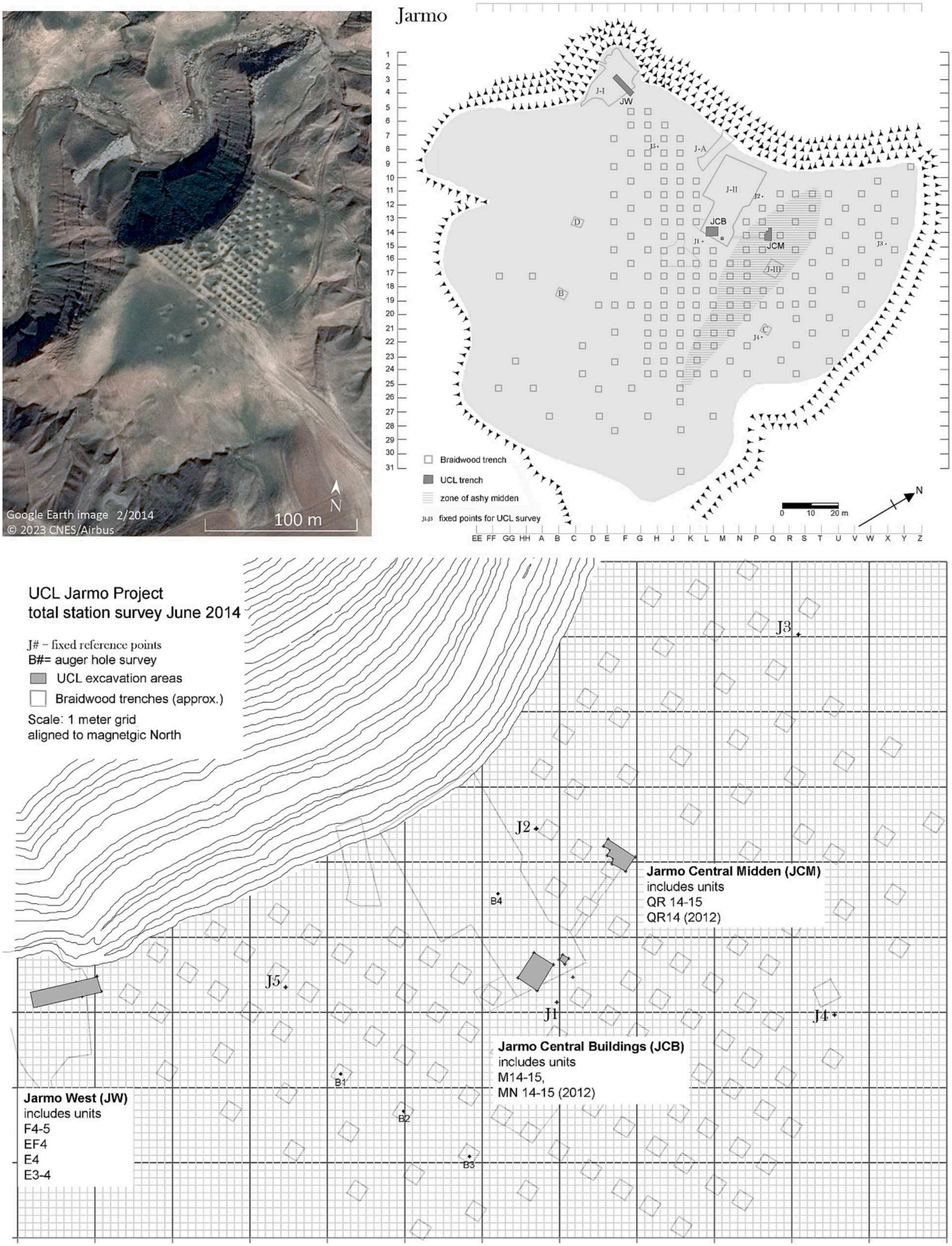

Fig. 2. Satellite photo of Jarmo from February 2014 (source Google Earth); a revised drawing of the Braidwood site sampling plan and grid, oriented on the basis of the Braidwood grid; a survey plan of the UCL excavation units in relation to the pre-existing Braidwood units, oriented to magnetic north. (Survey and planning by DQF, May 2014).

Fig. 3. Recent fieldwork at Jarmo, clockwise from top left: overview of site with eroded test trenches of Braidwoods (Sept, 2012), midden (JM) excavations (May 2014), step trench (JW) excavations (May 2014), buildings area (JCB) excavations (May 2014).

residue were quantified according to their volume (ml). All items present in the flotation samples from Jarmo were counted and quantified using standard archaeobotanical methods. As no subsampling was carried out, the calculation of the total number of items was straightforward and was based on the sum of the total number of items by botanical species, per sample. Amalgamation of samples was carried out for statistical purposes.

With the aim of producing new AMS radiocarbon dates to narrow Jarmo's chronological occupation span, 10 samples represented by pea and lentil seeds were submitted to the Scottish Universities Environment Research Centre (SUERC) for radiocarbon dating. Where standard pretreatment processes left insufficient carbon within the prepared graphite sample for a date, additional seeds from the same sample were added where possible, but in some cases even 3 or 5 five lentils combined still produced insufficient carbon after pre-treatment (See Table S1).

3.2. Microscopic analysis of food remains

Of the 83 archaeobotanical flotation samples collected from Jarmo, 18 samples contained charred food fragments. These 18 samples have yielded up to a total of 160 food fragments, with the amount of archaeological food fragments per sample varying between 0.1 and 2.5 ml in volume and sizes of fragments fluctuating from 0.1 to 1.1 cm. The largest and best-preserved specimens, adding up to a total of 28 food fragments, were selected for further microscopic analysis (see Table S6 for details). Amongst those which fit these criteria, a statistically representative number of food fragments from each excavation area was selected for in-depth microscopic analysis. Inevitably, the number of fragments selected from the JCM area was expectably higher given that more flotation samples were collected from the JCM in comparison with the other two areas.

Food fragments were preliminarily identified as fragments of archaeological food based on their starchy microstructure and porous matrix, which is indicative of well-processed and cooked plant components (Fig. 5). For this study, previously published methods based on high-resolution microscopy (González Carretero et al. 2017; González Carretero 2020) were applied with the aim of identifying any plant and animal components as well as potential cooking processes. Initial observation of the specimens was carried out using a Leica stereoscope S6D at magnifications of 8x to 50x. To record the observations made, images were created using a Leica EZ3 camera. Subsequently, further study was done under Scanning Electron Microscope (SEM). For this, specimens were first cleaned from soil sediments with a brush and sputter coated with ca. 1 μm of gold. Samples were examined using a Hitachi S-3400 N scanning electron microscope at the UCL Institute of Archaeology. Following initial observation of the fragments' surfaces, these were fragmented in order to observe their internal microstructures. SEM analysis included the study of the food matrix (microstrucures) through semi-quantitative recording of voids and plant particles and anatomical description of any included recognisable plant tissues. Microstructures and identified components of the selected food remains were subsequently compared with experimentally prepared cereal meals such as porridges, gruels, and bread (after González Carretero et al. 2017; González Carretero 2020).

4. Results

4.1. The archaeobotanical assemblage from Jarmo

In total 723 seeds, seed fragments and other plant remains were recovered and fully identified from Jarmo (see S5 for seed catalogue). Tables S2 and S3 contain full taxa counts and frequency and ubiquity percentages for the botanical remains identified from the Jarmo archaeobotanical assemblage. Overall, the total density of the assemblage is considerably low (0.16 seeds/litre of sediment) and the general state of preservation of plant remains varied from fair to good in some cases. It is also worth noting the low charcoal content recovered from

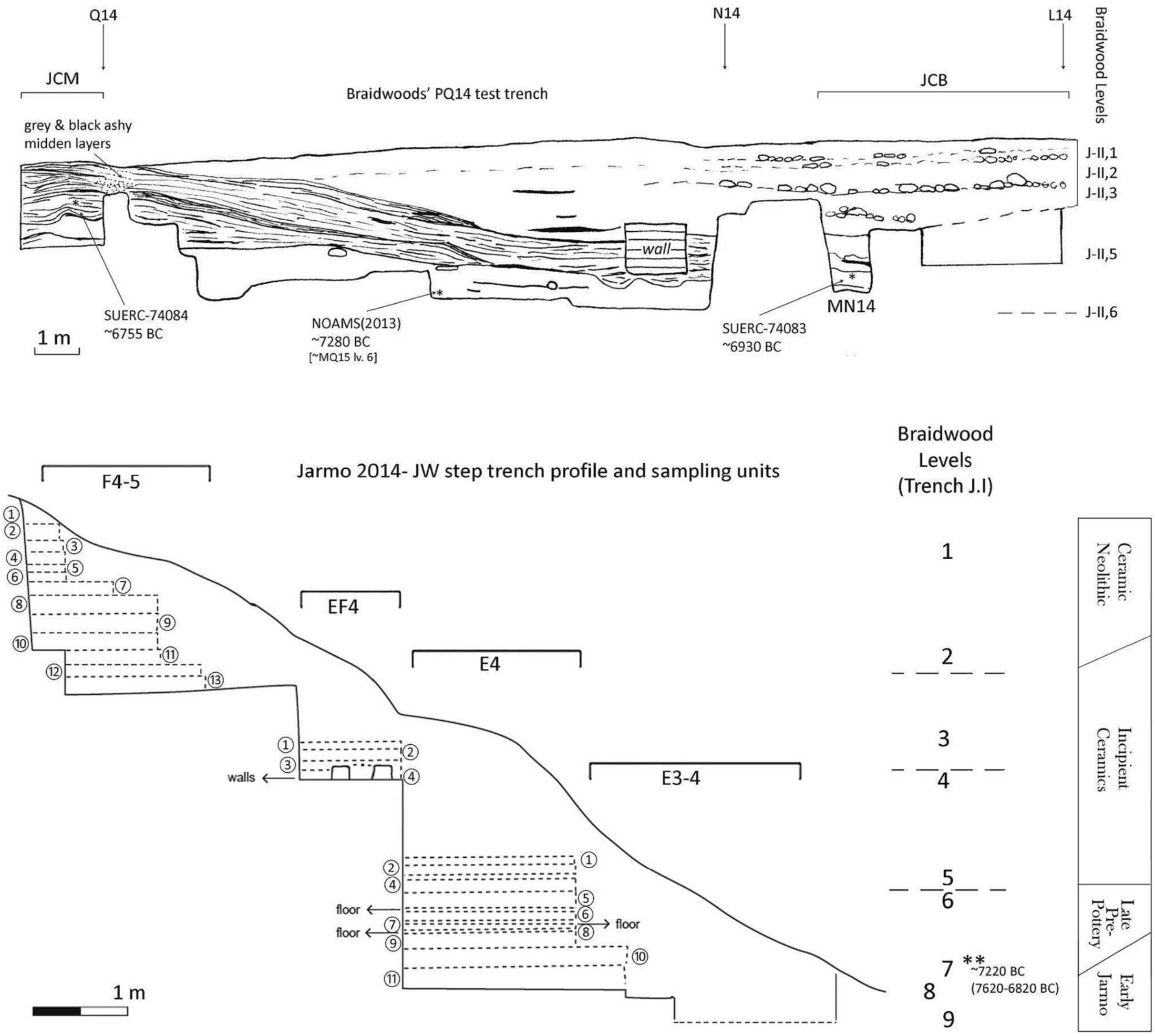

Fig. 4. Stratigraphy of Jarmo. Above: the JCM and JCB trenches represent along with the long North-South section excavated previously by Braidwood (1983). Below: sampling spits of the JW step trench represented in relation to J.I building levels of Braidwood (1983), and four suggested chronological phases.

flotation samples, with relatively few, highly fragmented wood remains in comparison to other sites across Southwest Asia and elsewhere.

The archaeobotanical assemblage from Jarmo is dominated by crops, with the presence of a variety of both cereals and pulses, in addition to charred food remains which represent the second most ubiquitous item in the assemblage (21.69 %). The presence of cereals in the archaeobotanical assemblage from Jarmo is attested mainly from the presence of glume wheat chaff (spikelet forks and glume bases), with the remains of cereal grains (kernels) being considerably lower in number. A high proportion of the glume wheat chaff from Jarmo is constituted by spikelet forks and glume bases of what is believed to be most likely emmer wheat (*Triticum* cf. *dicoccum,* 18.53 %), however, due to poor preservation and their fragmentary state, only a small portion (3.73 %) have been positively identified as derived from emmer wheat (*Triticum dicoccum*). Surprisingly, barley has a very low presence in the archaeobotanical assemblage from Jarmo having been identified only in the 6.02 % of the samples. This is believed to be of the naked type, and it is represented in the Jarmo assemblage by only 6 grains and no remains of chaff, constituting only 0.83 % of the total botanical remains. Similarly, virtually no remains of einkorn have been identified in the samples analysed by the UCL Jarmo Project, reducing the presence of this crop to an unclear emmer/einkorn grain. Amongst the pulses, lentil (*Lens culinaris*) has the highest ubiquity, having been identified in 37.35 % of the samples, followed by grass pea (*Lathyrus sativus*) and vetch (*Vicia ervilia* and *Vicia sativa*). Occasional remains of pea (*Pisum sativum*) have also been identified, but in much lower numbers than the other pulses.

Archaeobotanical analysis of the Jarmo assemblage further identified several economic species whose presence had not previously been reported at the site: free-threshing wheat (*Triticum aestivum/durum*), "new type" glume wheat (*Triticum timopheevii*) and flax (*Linum usitatissimum*). A total of 4 grains and no chaff from bread wheat have been identified in addition to only 1 grain and 2 spikelet forks from "new type" glume wheat. The presence of flax in the assemblage is slightly higher with ubiquity of 18.07 % and a total of 24 seeds and seed fragments. In order to assess their wild or domesticated nature, identified flax seeds from Jarmo were measured yielding a range of measures from 3.2 to 3.8 mm, which situate them within the domesticated type (*Linum usitatissimum*) (Weiss and Zohary 2011).

In terms of non-crop taxa and types, arable weeds and wild grasses, such as Poaceae (9.62 %) and *Galium* sp. (6.02 %), occur occasionally across the archaeobotanical samples followed by fragments of *Pistacia* sp. (4.82 %) and indeterminate nut remains (8.43 %). Other taxa and types identified include very occasional remains of Cyperaceae nutlets (3.61 %), often of *Bolboschoenus glaucus* type.

When comparing frequency of plant remains amongst the three excavation areas at Jarmo (Fig. 6; Table S4), midden contexts (JCM)

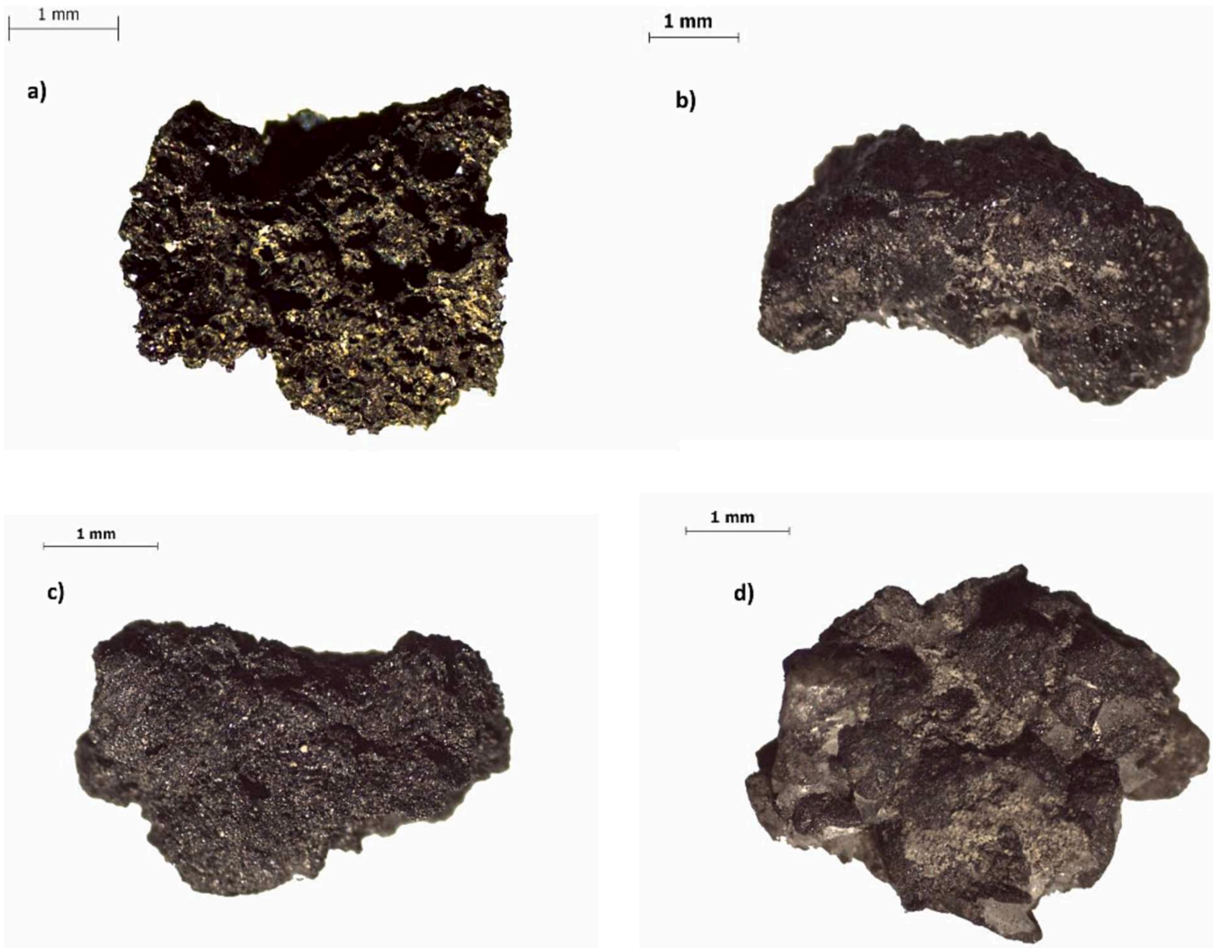

Fig. 5. Examples of charred food remains from Jarmo: a) Matrix type A - dough-like product; b) Matrix type B - naturally leavened bread-like product; c) Matrix type C - flat bread-like product; d) Matrix type D - porridge-like product.

yielded the highest number of plant items due to the larger number of samples collected from these contexts (55 out of 83 total samples collected) rather than it being a representation of plant density in the assemblage (0.15/L). The most frequently recovered plant remains from the middens at Jarmo are pulses and fragments of pulses, representing up to 40.49 % of the total midden assemblage. Amongst these, lentil is the most ubiquitous constituent of the assemblage having been recovered from 40 % of the midden samples. In contrast, remains of cereal chaff and arable weeds which would be typical of assemblages derived from crop-processing activities, only represent 20.59 % of the midden assemblage.

In contrast, despite only a small number of samples (c.17) collected from the Jarmo Central Buildings (JCB), this plant assemblage has the highest seed density (0.23/L) when compared to the other two excavation areas. Contrary to the pattern observed from JCM, cereal chaff (46.55 %) and, in particular, from emmer wheat (*Triticum dicoccum* and *Triticum* cf. *dicoccum)*, is the most frequent plant material recovered from this area. The high frequency of chaff contrasts with the low presence of grains and wild taxa of arable origin which constitute only 5.16 % of the assemblage from JCB, suggesting perhaps that certain crop-processing activities, such as pounding and dehusking of semi-clean wheat spikelets, were most likely carried out inside the houses (after Stevens 2014). This is similar to the glume wheat routine activity reported for house floor deposits at Neolithic Çatalhöyük (Bogaard et al. 2021).

4.2. Updated Jarmo chronology

The new radiocarbon dates were combined with some previously published dates to produce a revised chronological model of the sequence. Despite initial challenges with macrobotanical remains from Jarmo yielding insufficient carbon for C14 dating, two new radiocarbon dates were achieved by grouping 3 and 5 lentils from the same flotation sample. From JCB area, five lentil seeds were dated from Trench MN14, Layer 6, and provided a date of 7050–6710 cal. BC (2 sigma, SUERC-74083, 7980 ± 32 bp, '−23.8 ‰ d13C). From JCM, QR14 Layer 8, combined carbon from 3 lentils dated to 7030–6650 cal. BC (2 sigma, SUERC-74084, 7912 ± 30 bp, '-21.5 ‰ d13C).

Details on the selected dates can be found in the supplementary material, while Fig. 7 provides a Bayesian sequence model, with three phases. The middle Phase incorporates the Terminal PPNB and the initial ceramic period as identified in the JW step trench and the PQ Midden (Fig. 4). Recent excavations by Tsuneki and colleagues (Tsuneki et al. 2019) have also recovered material that dates to this Terminal PPNB phase.

In the light of these new dates and their correlation with the Braidwood's sequence, we propose a new and revised phasing of the site summarised in Table 1. The very earliest levels (Early Jarmo) are not directly dated, and perhaps stretch as early at 7600 BCE, but occupation was certainly established by 7400–7200 BCE before the formation of the large ashy midden, which has dates starting ca. 7000 BCE.

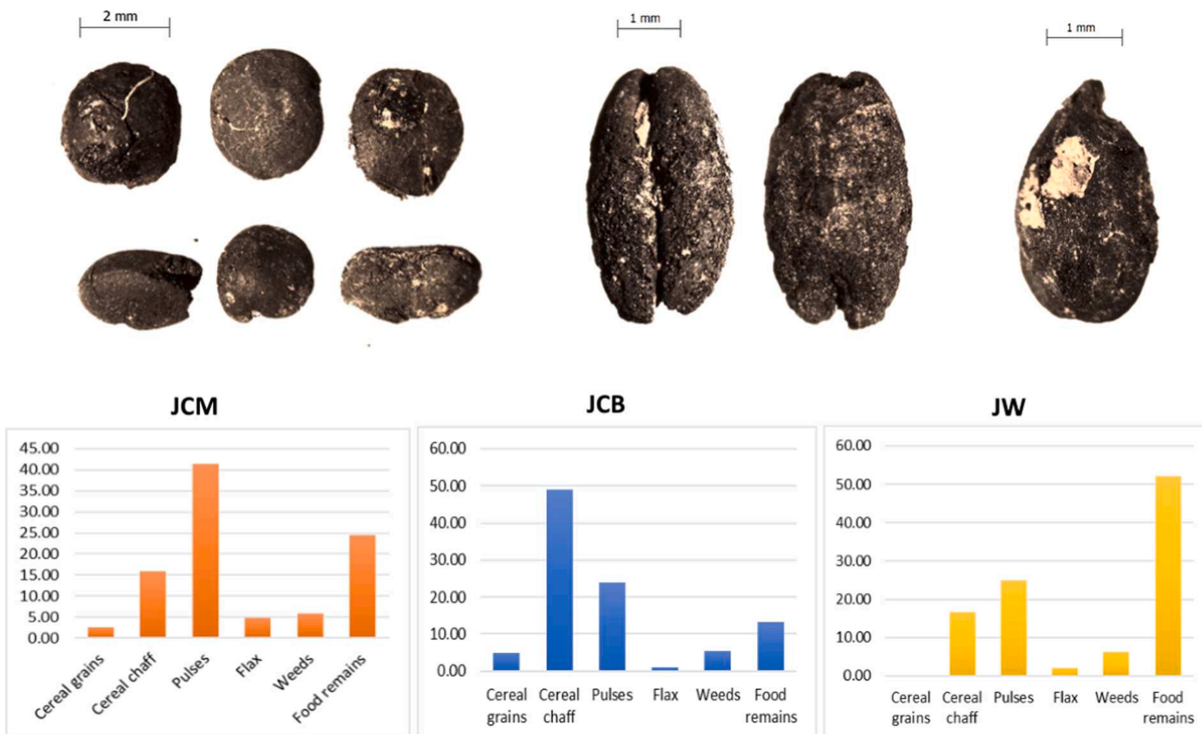

Fig. 6. Bar chart showing frequency percentages of plant remains recovered from Jarmo midden deposits, Jarmo Central Buildings and Jarmo West.

4.3. *Food preparation and cooking at Jarmo*

Morphology and microstructure.

Archaeological food remains recovered from Jarmo were compared with experimental reference materials generated by five sets of experiments established as part of the first author's PhD project (González Carretero et al. 2017; González Carretero 2020). In accordance with previously published results (*idem*) and based on the internal characteristics shared between experimental and archaeological food microstructures, we were able to distinguish four distinct cereal product categories amongst the analysed food remains from Jarmo (Fig. 8). Subsequent descriptions and categorisation of food types from Jarmo are after González Carretero (2020).

Two types of food categories with high-porous microstructures were identified at Jarmo. The first type of microstructure, *Matrix Type A,* showed similarities with uncooked dough-like experimental products as it presented very few and small visible particles (0–2; 50–600 μm) but large closed voids, from 200 to 800 μm, which cover a high percentage of the microstructure surface (>30 %). A second type of porous microstructure, *Matrix Type B,* was identified at Jarmo and, although this matrix also presents a very low number of medium visible particles (1–3; 200–900 μm), in this case air bubbles or voids are represented by micropores (50–300 μm) covering more than 30 % of the surface. These microstructure features were found to resemble those of naturally leavened experimental breads.

Besides the porous matrices, two additional microstructures with lower porosity percentages have been identified. The third type of microstructure or *Matrix Type C* has a relatively low number of small and medium visible particles (1–4; 50–900 μm) and a low percentage of small, closed voids and micropores (25–300 μm), covering between 10 and 20 % of the surface. This matrix was seen to correspond with those of flat bread (unleavened) experimental products. The fourth and last type of identified matrix from Jarmo or *Matrix Type D,* however, presents a unique microstructure, characterised by a "lumpy" appearance with a very high number of large visible particles (4–15; 500–1800 μm) and a medium percentage of large (200–500 μm) cracks and channel voids (10–20 %). This matrix was seen to be strikingly like that of porridge-like experimental products, i.e. where cereals were boiled within a liquid, and in this case, water. In the case of *Matrix Type D*, large particles seen in the matrix were represented by fragments of broken cereal grains and pulses which presented particular features associated with specific preparation and cooking processes. Visible grain fractures observed in those fragments identified as porridge-like products showed a glassy appearance which is likely associated with a highly gelatinised endosperm (Valamoti et al. 2008; 2021). This is undoubtedly a result of pre-treatment and cooking processes involving liquid, as seen for experimental *bulgur* and *trachanas* (Valamoti et al. 2021).

In summary, *matrices Type A*, *B* and *C* and, therefore, dough and bread-like products are characterised by a low number (0–3) of small and medium visible particles (50–900 μm). On the other hand, porridge-like products, or *Matrix Type D*, are characterised by its clearly bigger (500–1800 μm) and numerous (4–15) visible plant particles which correspond to grain and pulse fragments and very large bran cells areas. In addition, there are differences in the types of voids in the different matrices. *Matrix Type A* and *B* fragments contain a very high percentage of air bubbles or closed voids (ca.30 %) in contrast to *Matrix Type C* and *D* fragments which have a medium percentage of voids (ca. 15 %). In total, the average number of particles observed in the food fragments from Jarmo is 1.57 and their average size is 0.33 mm. In terms of voids (air bubbles), the average size of the voids is 0.11 mm and the average of matrix coverage is 14.57 %. In comparison with modern flat breads, the particle measures show similar average and sizes highlighting the importance of the use of fine or relatively fine flour for the preparation of most of these foods at Jarmo.

- Plant components

There is a general consistency in the plant food composition of the Jarmo food fragments with 87.80 % of the plant particles having been identified as broken cereal grains and fragments of internal tissues of the cereal kernel. Additionally, a total of 12.2 % of the plant components observed under SEM were identified as non-cereal plant ingredients

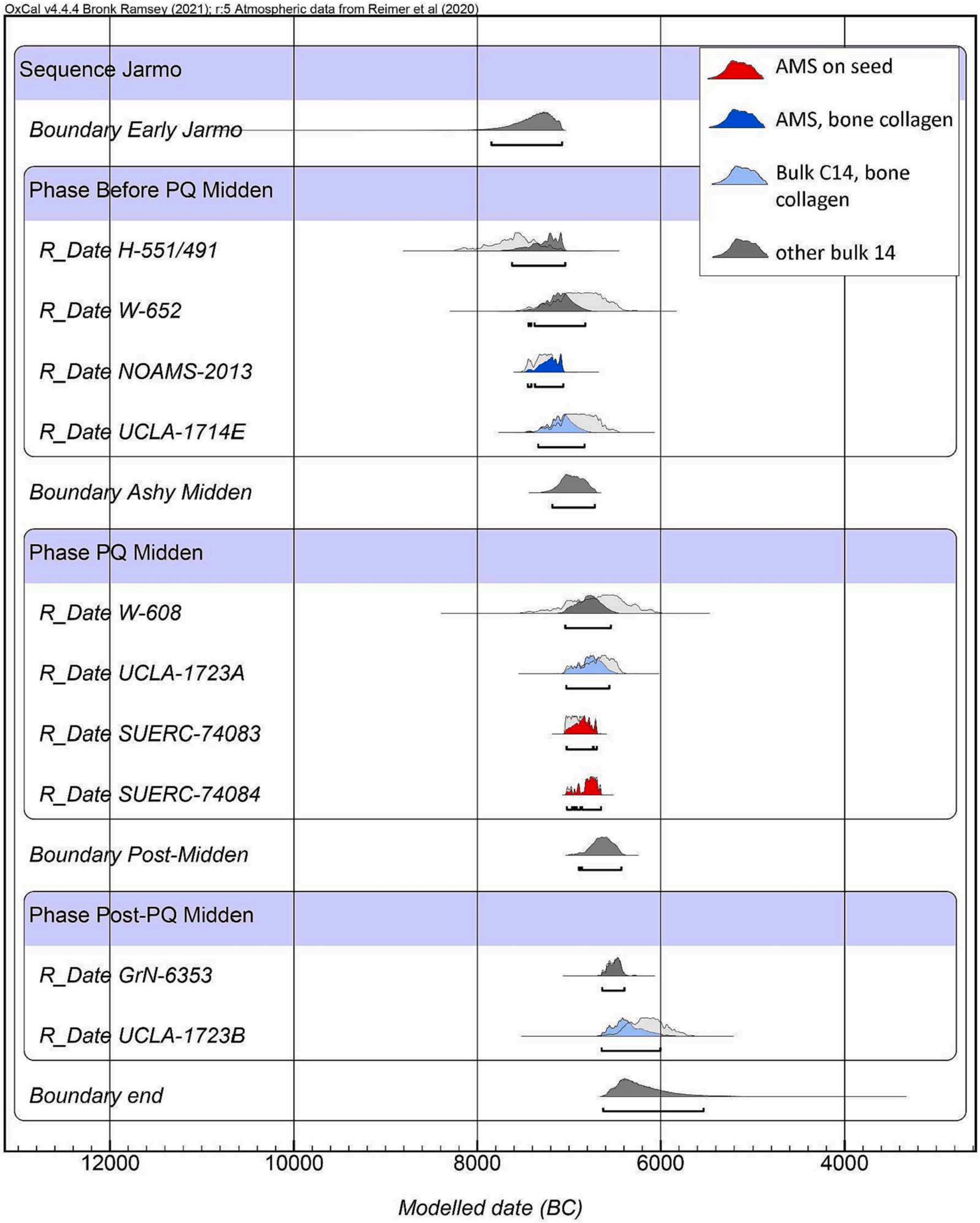

Fig. 7. Modelled radiocarbon dates from the Jarmo sequence. For data see Table S1.

Table 1
Revised chronology for Jarmo.

Hypothetical Chronological Phase	Braidwood J. I	J.II and elsewhere	UCL: JW (=E or F)	JCB (=MN14)	JCM (=QR14)
Phase 4: Late Neolithic (ca.6600–6300 cal. BC)	J-I, 1	J.II.1–2, Upper midden of J. III	F4-5 (L.1–9)		Layers A-B (Up to spit 7)
Phase 3: Pottery Neolithic (ca.6800–6600 cal. BC)	J-I, 2	J-II, 3J-III	F4-5 (Layers 10–13)	M14-15MN14, 1–4	Layer C-D (spit/layers 8–16)
Phase2: Terminal PPNB and Incipient Pottery (ca.7000–6800 cal. BC)	J-I, 3	J-II-4–5	EF4, 1–3	MN14, 5–11	Layer E (16–21) QR14 – 9
Phase 1: Middle To Late PPNB (from ca. 7400 BCE to 7000)	J-I, 4–9	J-II, 6 and below (unexcavated)	Lower EF4 (4,5) E4 E-3–4		(Pre-Midden)

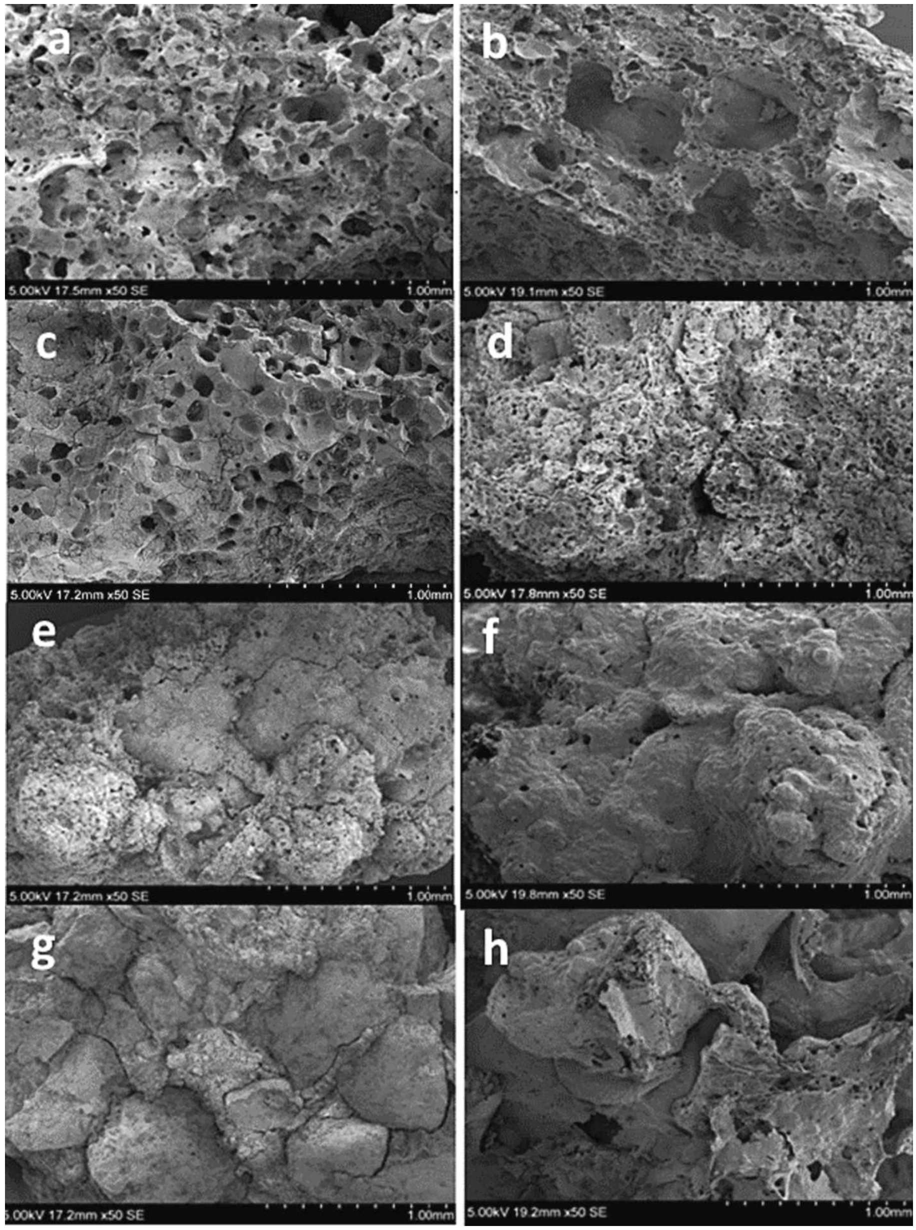

Fig. 8. Comparison of archaeological food matrices from Jarmo (a, c, e and g) and experimental food matrices (b, d, e and h) (after González Carretero et al. 2017; González Carretero 2020). *Matrix Type A* equivalent to dough-like products (a, b); *Matrix Type B* equivalent to possible leavened bread-like products (c, d); *Matrix Type C* equivalent to flat bread-like products (e, f); *Matrix Type D* equivalent to porridge-like products (g, h).

(Fig. 9).

Among the cereal tissues identified, pericarp tissues and endosperm cell structures were the most observed, specifically fragments of bran cell layers (transversal and longitudinal cells), aleurone layers and endosperm starch containing cells. In some cases, the identification of cereal components to specific genus, such as wheat and barley, was possible, due to their cell and tissue shapes, sizes, and patterning. Fragments of bran, which include longitudinal and transverse cell layers present in the pericarp of cereal kernels, are by far the most found particles among the food remains from Jarmo (Fig. 10). A total of 32 fragments of bran cell layers have been identified in the food fragments from Jarmo, representing 39.02 % of the total identified particles. Bran cells occurred in 15 of the 28 analysed samples (ca. 53.57 %) with an area size of 20 to 1400 μm. The distinction between wheat species (*Triticum* sp.) and barley (*Hordeum* sp.) transverse cells have been generally possible and was made following previous established criteria (Dickson 1987, Holden 1990, Colledge 1989; Heiss et al. 2015; 2017) and the use of reference sources (Winton and Winton 1932) and experimental materials (González Carretero 2020). This was aided by the identification of aleurone cell tissues, both single-celled attributed to wheat species present at Jarmo and multiple-celled ones characteristic of barley species (Fig. 11).

The food remains from Jarmo are characterised by the large number of small particles (<500 μm) in contrast with the small number of large grain fragments identified in the food microstructures. A total of 14 fragments of grain from 3 different food fragments were identified among the 28 analysed fragments from Jarmo, representing only the 17.07 % of the identified particles. This contrasts with results obtained from the Neolithic site of Çatalhöyük East where fragments of grains were present in up to 40 % of the analysed food fragments (González Carretero 2020). This low quantity of broken grains among the food fragments from Jarmo suggests the higher use of fine flour over coarse flour for the preparation of cereal products. Moreover, there is a very low presence of barley particles identified among the analysed food

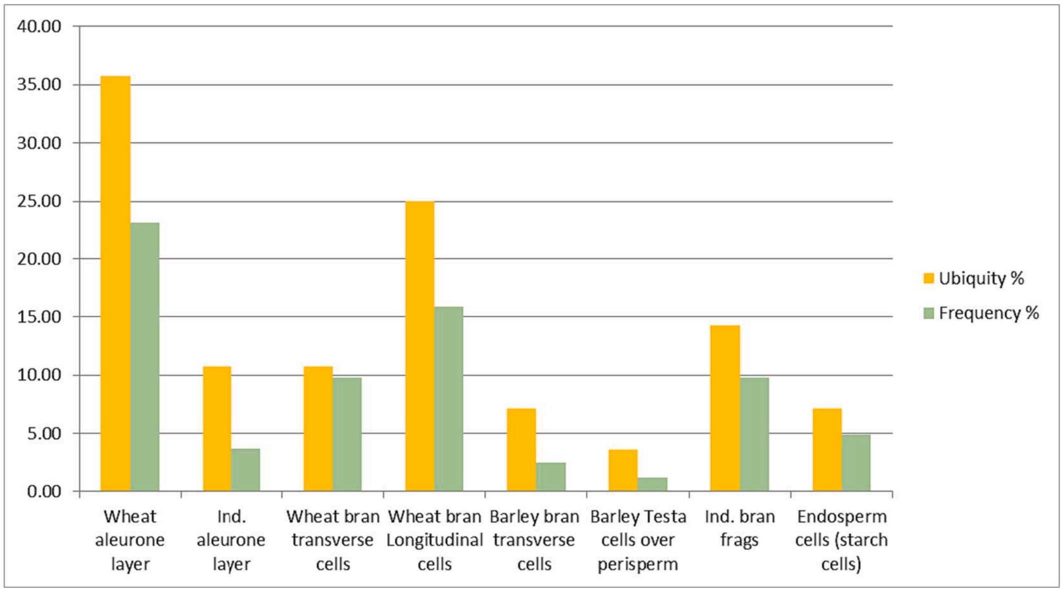

Fig. 9. Ubiquity and frequency of different types of cereal components identified in the analysed food fragments from Jarmo.

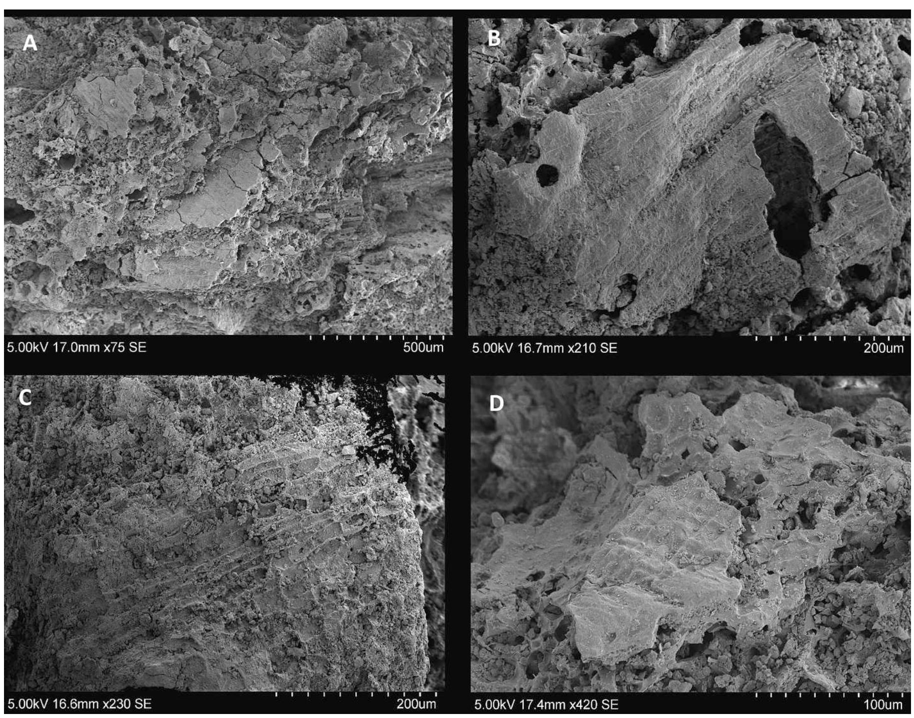

Fig. 10. SEM micrographs showing a range of fragments of cereal pericarp tissue or *bran* (longitudinal and transverse cells) identified in food remains recovered from Jarmo. A) Micrograph showing area of the food matrix with accumulation of bran fragments; B) Example of small *Triticum* spp. bran fragment (<500 μm) with visible longitudinal cells; C) Example of small Hordeum vulgare bran fragment (<500 μm) with visible transverse cells; D) B) Example of small *Triticum* spp. bran fragment (<500 μm) with visible longitudinal cells and single aleurone layer in cross-section.

fragments from Jarmo with only two barley bran fragments from two different food samples Fl.155 and Fl.175.1 having been identified. In the cases where barley particles were identified, these were always accompanied by wheat particles, which suggest the deliberate mixing of barley with wheat and could further indicate a preference for the use of wheat species for the elaboration of these meals.

The food remains recovered from Jarmo also showed a small amount of non-cereal components. However, the proportion of the non-cereal components among the samples from Jarmo is very low, reduced to only two samples which contained fragments of processed pulses (ca. 7.5 % of the assemblage) (Fig. 12). The particles identified are fragments of seed coats from pulses (palisade layer and *testa*) and, as seen from similar food assemblages like those from Neolithic Çatalhöyük, different types of pulses have been identified mixed in the food fragments and accompanied normally with wheat components such as bran fragments and aleurone layers. Despite pulses and, in particular lentils, being the most ubiquitous and frequent plant remain at the site, the presence of pulses in the food fragments from Jarmo is limited to a couple of samples recovered from contexts from Phase 3 of the occupation (ca. 6800–6500 cal. BC).

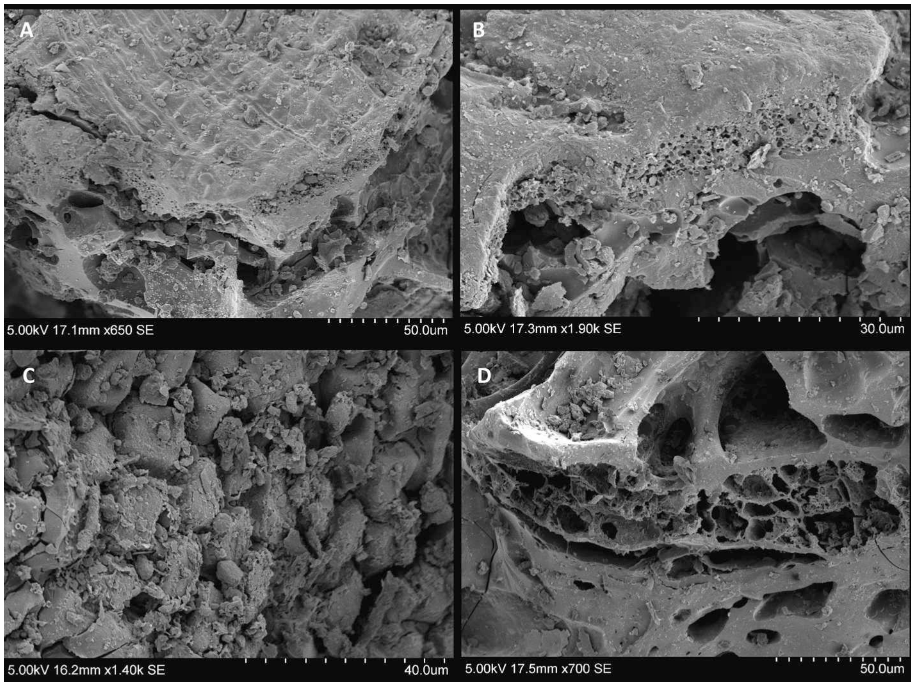

Fig. 11. SEM micrographs showing a range of examples of aleurone cell tissues identified in food remains recovered from Jarmo. A) Detail of grain fragment with visible single-celled aleurone layer identified as wheat (*Triticum* spp.) in accordance with Jarmo's archaeobotanical assemblage); B) Detail of cross-section of aleurone cell layer with visible, preserved aleurone protein; C) Detail of aleurone cells and aleurone protein in bird view; D) Cross-section of multiple-celled aleurone layer with up to three rows of aleurone cells.

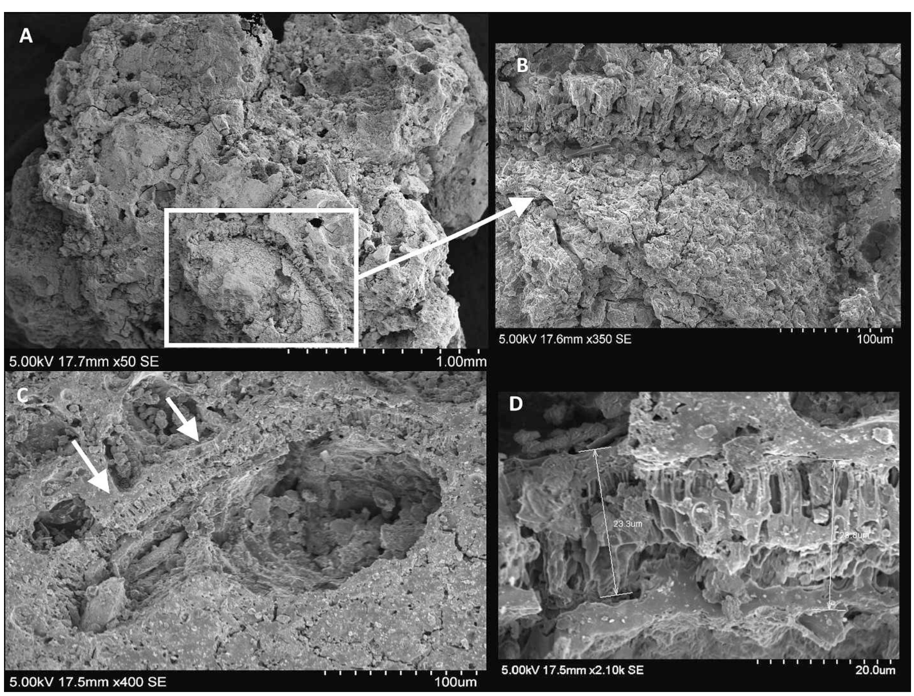

Fig. 12. SEM micrographs showing a range of fragments of pulses and associated cell tissues identified in food remains recovered from Jarmo. A) Food fragment with fragment of pulse embedded in its matrix; B) Detail of fragment of pulse showing *testa* (seed coat) tissues, including palisade layer and *testa* pattern. This was identified as potential vetch *Vicia* spp. judging by the palisade layer's thickness and *testa* patterning; C) Fragment of pulse with visible seed coat cross-section with palisade and hor-glass cells; D) Detail of palisade and hour-glass cells with measurements.

5. Discussion

5.1. Re-evaluating early crop agriculture at Jarmo

Early crop agriculture is attested at Jarmo by the presence of both cereals and pulses with the latter being the most ubiquitous in the archaeobotanical assemblage. Although first archaeobotanical analysis of plant remains from Jarmo excavations by the Braidwoods in the 1950's (Helback 1959; Helbaek 1960) produced some of the earliest evidence of the presence of domesticated wheat and barley species in the

Zagros area, considerations of the importance of pulses in the diet of this community appear to have been of lesser importance. Despite identification of a range of species, with mentions of lentil (*Lens culinaris*) field pea (*Lathyrus* sp.) and vetch (*Vicia* sp.), specifications about density or frequency of these in the assemblage or suggestions about these being of the wild or domesticated type were lacking. Pulses played a key role in early agricultural practices as one of the main plant types within the 'Fertile Crescent' Neolithic founder crops being amongst the first ones to be domesticated during the Pre-Pottery Neolithic period, 11,000–10,000 years ago in Southwest Asia (Weiss and Zohary 2011). In the Central Zagros Area, pulses have been regarded as extremely valuable food resources from the Palaeolithic to today, having evidence of Upper Paleolithic communities purposely gathering and managing their yield from the end of the Younger Dryas, ca. 10,650 cal. BP at the sites of Ghar-e Boof Cave and Chogha Golan (Baines et al. 2015; Baines 2017; Kabukcu et al. 2023). Amongst the pulses, analysis of the newly recovered archaeobotanical assemblage from Jarmo has shown the reliance of its inhabitants on lentils as one of the staple crops during the occupation of the site. Lentils have been recovered in abundance from Jarmo, being the most ubiquitous remains in the plant assemblage, with a presence and frequency well above cereal crops. Although pulses have received little attention, their high abundance in the archaeobotanical record is attested from other early Neolithic sites in this area. The site of Ali Kosh in Iran yielded one of the earliest accounts of a high concentration of domesticated lentils in the Zagros Mountains (*Lens culinaris*) dating back to ca. 7500–6600 cal BC (Helbaek 1969; Hole 2000). Similar deposits of lentils have been recovered from early Pre-Pottery Neolithic sites in other areas of Southwest Asia like Çayönü in Southeastern Turkey (van Zeist 1972; van Zeist and de Roller 1994, 2003), Gusir Höyük in the Upper Tigris basin (Kabukcu 2023), Yiftah'el, north Israel (Garfinkel, et al. 1988) and Ahihud (Caracuta et al. 2017). The establishment of lentils as the main legume crop in the Zagros area is evidenced by archaeobotanical work on Ubaid, Uruk and Halaf sites where large storage deposits of charred lentils have been recovered. Examples of this are the sites of Tepe Marani and Gurga Chiya on the Shahrizor Plain, the latter having yielded a 30 cm deep deposit of carbonised lentils within a storage bin (Carter et al. 2020).

Cereal crops, however, are less visible in the macrobotanical assemblage recovered from the latest Jarmo excavations. Remains of cereals are reduced to the presence of glume wheat chaff and a few wheat and barley grains scattered throughout sampled layers. In contrast with Helbaek's first archaeobotanical analysis in which he identified remains of two glume wheat species, einkorn and emmer (*Triticum monococcum* and *Triticum dicoccum*) (Helbaek 1960, 107), analysis carried out as part of the UCL project did not identify remains of einkorn and only a hand-full of glume bases allowed for positive identification as emmer wheat. Given the limited illustration of wheats by Helbaek, and early stage in the history of archaeobotany, it is plausible that his reported einkorn in a mistaken identification. Two further species of wheat were identified during the latest analysis: free-threshing wheat (*Triticum aestivum/durum*) represented by a small number of grains and new type glume wheat (*Triticum timopheevii*). Although the remains of these represent a very low portion of the cereal crops recovered from Jarmo, they provide very early evidence of the presence and use of these taxa in the Zagros area.

The presence of *timopheevii* wheat at Jarmo is significant as this represents the earliest in the Zagros, and marks out evidence for an eastward dispersal of this crop (Fig. 10). Together with evidence from Sheikh-e Abad, Iran (ca. 7600 BCE) it indicates an early presence of this species of wheat in the eastern Fertile Crescent (Whitlam et al. 2018). Early occurrences of this taxon are associated with domestication in Anatolia (Czajkowska et al. 2020; Charles et al 2021; Roushannafas et al. 2022), followed by rapid spread both west and east. This morphological taxon has only been recognised by archaeobotanists as a distinct taxon in the past 30 years (Jones et al. 2000), with increasing recognition of its presence in the ancient Near East and Europe. Recent aDNA analysis confirms that these are AAGG tetraploids represented today by a rare relict crop *T. timopheevii* (Czajkowska et al. 2020)*,* but we should expect that modern timopheevii represents only a limited subset of previously greater variation in this taxon. The modern wheat genomic study of Pont et al. (2019) recognized two distinct lineages within *timopheevii,* which could result from multiple domestications or early geographical divergence among cultivars—such westward and eastward dispersing lineages. The earliest finds are ninth millennium BC, from Cafer Höyük, levels IX-X (De Moulins, 1997, described as "machoid emmer"), which date back to ca. 8400–8000 BCE, and, although morphologically wild and in small quantities of similar age from Boncuklu Höyük in the Konya plain (Baird et al., 2018). This wheat type was also found throughout the sequence at Aşikli Höyük in central Anatolia (8400–7500 BCE) where it was a mixture of morphologically wild (shattering) and domesticated types (Ergun 2018; Ergun et al. 2018). At Çatalhöyük (7100–5950 BCE), rachises of *T. timopheevii* continued to evolve towards non-shattering dominance (Charles et al 2021) when it came to dominate over emmer wheat during the middle of the sequence (Charles et al. 2021; Roushannafas et al. 2022). Elsewhere in Neolithic Anatolia this is also the case at sites such as Yumuktepe on the southern coast (Ulas and Fiorentino 2021). Genetic data from modern *Triticum araraticum,* the wild progenitor of *T. timopheevii,* indicate geographically structure in the genomic variation, and support derivation of modern timopheevii only from the Southwestern parts of that range, from wild populations in southern Anatolia (Mori et al. 2009). While modern populations may have shifted due to climate change or become more restricted due to habitat destruction, the broader geographical structure implies no long-distance dispersal event prior to cultivation. We can therefore conclude from the archaeobotanical and modern wild evidence that cultivation and domestication was underway in Anatolia between the upper Euphrates Valley and the Konya plain, from which this species spread both westward to Europe and eastwards into the Zagros region. Finds in northern Iran and at Djeitun in southern Turkmenistan (Charles and Bogaard 2010; Fuller 2014; Roustaei et al. 2015); also indicate a Neolithic dispersal of *timopheevii* alongside emmer and einkorn in the Neolithic, while this wheat's presence in Neolithic Europe is now well established (Jones et al. 2000; Toulemonde et al 2015; Ulaş and Fiorentino (2021)) (see Fig. 13).

In addition, macrobotanical analysis reported here has revealed the presence of early domesticated flax at Jarmo. This is of relevance as it represents one of the earliest examples of the use of flax by Neolithic communities in the area. Large-seeded flax remains from Jarmo were recovered from the earliest levels of the site excavated from the step trench (EF4, 5, estimated to date prior to 7000 cal. BC) to the later layers excavated from the midden deposits (QR14-15, 22) and, in accordance with the revised chronology, these remains of flax seeds might just be among the earliest to date in the Zagros area. Helbaek (1969) had previously identified small-seeded flax from the earliest levels (ca.7500–6750 BCE) at Ali Kosh in southwest Iran, whose measurements placed them closer to the wild progenitor of domesticated flax (*L. bienne*) than the domesticated type. Other early reports of domesticated flax come from the site of Choga Mami and date back to ca. 6000–5600 cal. BC (Helbaek 1972). However, during the early Neolithic in Southwest Asia, flax was also found in the form of fibres, for example from the Pre-Pottery Neolithic B site of Tell Halula (Syria), 7600–7300 BCE, where flax was found as twined cloth fragments (Alfaor Giner (2012)), and netted/knitted finds from Nahal Hemar (Israel), directly dated by AMS to ca. 7500 BCE (Schick 1988).

5.2. Plant use and Neolithic food recipes

Among the plant ingredients identified in the food fragments from Jarmo, there is a consistency in the presence of domesticated crops such as cereals and pulses, having identified particles from these in almost 90 % of the analysed fragments. Among these, four or five pulses lentil–pea, grass pea and two types of vetch (*Lens culinaris*, *Pisum sativum,*

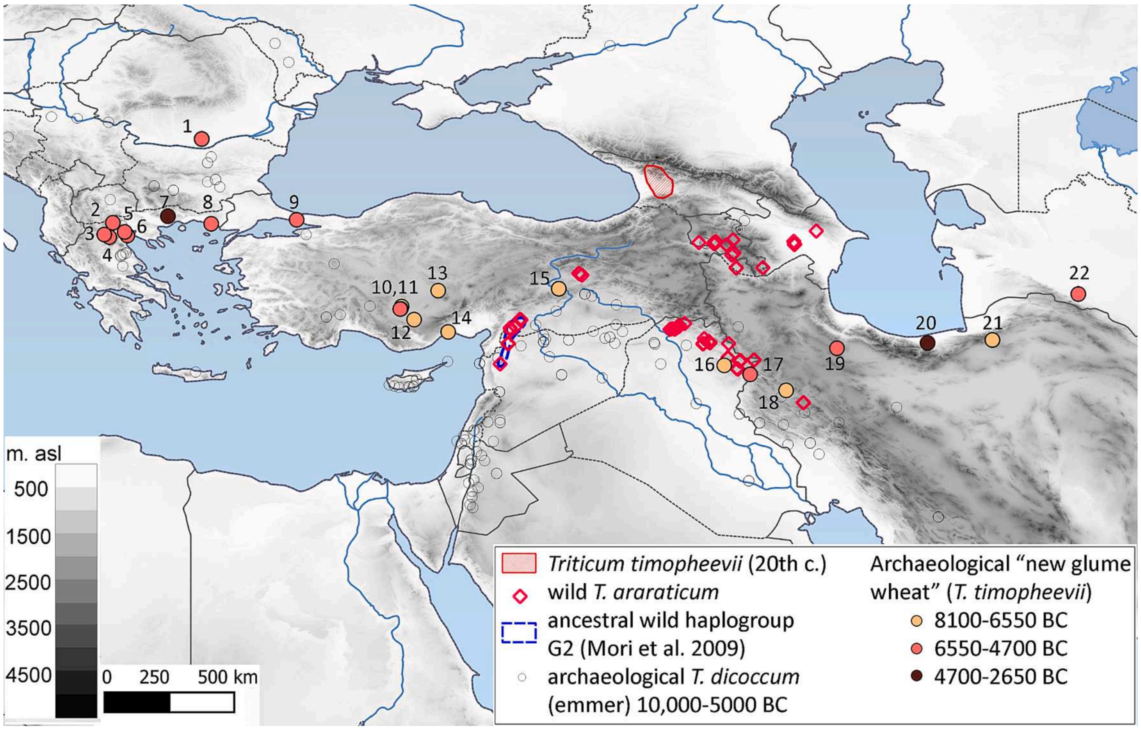

Fig. 13. Map of archaeological distribution of *Triticum timopheevii* (AAGG) glume wheats versus emmer wheat (*T. dicoccum* AABB), in relation to the wild distribution of *T. araraticum* (AAGG) and 20th century relict cultivation *T. timopheevii* (in modern Georgia). Mori et al. (2009) infer the ancestry of *T. timopheevii* in the western most wild *araraticum* populations that share with the domesticate chloroplast haplogroup G2. Representative sites of Archaeological *T. timopheevii* sites numbered: 1. Magura-Buduiasca; 2.Apsalos; 3. Mayropigi-Phllostari; 4. Kremasti Koiladas; 5. Paliambela; 6. Makriyalos; 7. Arkadikos; 8. Makri; 9. Yenikapi; 10. Catalhoyuk (East and West); 11. Boncuklu; 12. Can Hassan III; 13. Asikli Hoyuk; 14. Yumuktepe; 15. Cafer Hoyuk; 16. Jarmo; 17. Tepe Marani; 18. Sheikh-e Abad; 19. Tepe Khalesh; 20. Ghal e-Ben; 21. Sang-e Chakhmaq (East and West); 22. Jeitun. There is no claim for comprehensive representation of all/recent discoveries in the European area. Note that archaeological emmer wheat normally co-occurs with *T. timopheevii,* so light open circles indicate sites where *T. timopheevii* has not been reported.

Lathyrus sativus and *Vicia ervilia/sativa*) and cereals, barley (*Hordeum vulgare*) and wheat species (*Triticum* sp.), are the most likely ingredients of the Neolithic cereal-based meals from Jarmo.

The cereal particles identified in the analysed archaeological food fragments from Jarmo did not allow for identification of the observed wheat (*Triticum* sp.) or barley (*Hordeum* sp.) cell tissues to the species level due to transverse and longitudinal cells (bran) being highly degraded and incomplete. However, based on the macrobotanical assemblage, three wheat species are likely, including emmer wheat (*T. dicoccum*), 'new type' glume wheat/ timopheevioid wheat (*T. timopheevii*) and bread wheat (*T. aestivum*) in addition to naked barley (*Hordeum vulgare* var. *nudum,* probably six-row *H. hexastichum* var. *coeleste*).

Due to the low number of buildings excavated at Jarmo, the differential use of these crops for daily activities at the site is currently unknown. However, archaeobotanical evidence suggests the presence and use of these species throughout the occupation sequence at the site. In general, among the cereals, emmer/new type glume bases outnumber remains of bread wheat and barley which suggests that glume wheat was predominant throughout the sequence. In relation to pulses, lentil is the most ubiquitous and frequent plant material from Jarmo throughout the sequence and its high presence suggests the wide use of lentils in the preparation of daily meals. Due to the variety of pulse seed coats identified among the pulse tissues identified in the food fragments, it is safe to assume that not only lentils were used for the preparation of these meals, but also other species, most likely pea or grass pea as the thicker seed coat suggests.

The remains of food recovered from Jarmo have made possible the identification of different types of Neolithic food products or recipes (Table 2). Remains of flat bread were the most common food remains recovered from Jarmo, followed by porridge-like products, a pattern noticed from other assemblages like that of Çatalhöyük East (Fig. 11). Flatbreads at Jarmo were made using mainly wheat fine flour, in addition to the use of barley in small quantities in Phase 1 (ca. 7400–7000 cal. BC). Flatbreads analysed from Phases 2, 3 and 4 only contained remains of wheat in addition to several particles which did not allow for genus identification due to their degradation. Only one fragment each of a dough and a leavened bread-like product were identified among the analysed food fragments from Jarmo, indicating the predominance of flat breads.

Remains of porridge-like products are the second most commonly recovered food type from Jarmo, however as mentioned above, they are absent from Phase 1 and become more common from the middle Phase 2 onwards (after ca.7300 cal. BC). Porridges recovered from Phases 2 and 4, are made purely using cereals, in particular wheat, while those from Phase 3 also contained particles of pulses (possible lentil, bitter vetch

Table 2
Summary of types of cereal-based products and their identified ingredients through time.

Chronology Phase	Recipes Matrix Type	Product	Ingredients Wheat	Barley	Indet. Cereal	Pulses
Phase 1	C	Flat bread	x	x		
Phase 2	A, B, C, D	Dough, flat bread, leavened bread, porridge	x		x	
Phase 3	C, D	Flat bread, porridge	x		x	x
Phase 4	C, D	Flat bread, porridge	x		x	

and other larger pulses such as pea or grass pea as attested by different measurements of the seed coat). Interestingly, like the results from Çatalhöyük East, the only type of food product which contains pulses are porridges. In this sense, the case of Jarmo is even more particular, as pulses represent the majority of the macrobotanical assemblage; however, only two porridge-like samples have produced evidence of their use for the preparation of cereal products. In this sense, it seems highly possible that these porridge-like products which contain pulses are representative of a type of legume-based gruel or thick "soup".

6. Conclusions

The recent UCL project at Jarmo, targeting systematic archaeobotanical sampling and research, has confirmed that the site represents an early agricultural community in the eastern Fertile Crescent at which domesticated cereals, pulses and flax were cultivated and transformed into food stuff as part of a bread-based *cuisine*. Pulses and, in particular, lentils dominate the archaeobotanical assemblage representing the main source of plant food at the site. Despite the overall lower presence of cereals and specifically grains in the archaeological record from Jarmo, cereals were an essential food source for the Jarmo community as shown by the recovery of remains of cereal-based products (e.g. bread, porridges).

The archaeobotanical study of plant remains from Jarmo indicate that throughout most of the occupation wheat-flour flatbreads and porridge-like products appear to be two of the main type of meals prepared and consumed by the Jarmo community, alongside the use of lentils, likely used in a variety of stews or soups. Barley, however, appears to have been a minor component in the preparation of cereal-based products with a few examples of barley particles present in food fragments analysed from the earliest levels at the site. As documented by Braidwood et al. (1983), houses in the early preceramic levels of site included domed oven features (*tabun*) (e.g. Building J.II.6: Braidwood et al 1983) and clay lined pits that might have also served as roasting or baking facilities. Thus, there was labour investment in the material features from bread-making from the initial occupation of the site, indicating the site's founders, perhaps as early as the early 8th millennium BC, were carriers of a "grinding and bread culinary tradition" (Fuller and Rowlands 2011) or "bread centered Neolithicity" (Fuller and González Carretero 2018). Jarmo's inhabitants' diets were complemented by pulse-based soups/stews from at least 6800 BCE, by which time some ceramic vessels began to be present on the site, although these could have also been cooked and served in the stone vessels that were well-documented through Braidwood's earlier excavations.

While some early cultivating communities in the Near East during the Pre-Pottery Neolithic have been inferred to have "intermediate" or mixed-subsistence economies that still relied on significant quantities of wild plant foods even as late as the Seventh Millennium BC (Fuller et al. 2018; Lucas and Fuller 2020), Jarmo was strongly reliant on agriculture and crop-based foods already by early in the Eight Millennium BC.

Author contribution statement.

LGC and DQF carried out study conception and design, DQF and CS carried out data collection, LGC and LL performed analysis of archaeobotanical samples. Microscopic analysis (SEM) of food remains were done by LGC. LGC and DQF carried out interpretation of results and LGC, LL, CS, DQF contributed to manuscript preparation. The authors declare no competing interests.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Link to the UCL repository of the first's authors PhD thesis which contains of additional data has been shared.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2023.104264.

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