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Storage story: Investigating food surplus and agricultural methods in Late Ubaid Gurga Chiya (Iraqi Kurdistan)

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ABSTRACT

The world's earliest documented transition from village to urban life took place in Mesopotamia during the fourth millennium BCE. In order to recognize the steps leading to this process, archaeologists have long focused on the development of village life in the preceding 'Ubaid period, corresponding broadly to the 5th millennium BCE. Our research aims to contribute to this ongoing process by presenting new evidence pertaining to changes in agricultural methods and the organization of food surplus from a site of the Late 'Ubaid period called Gurga Chiya, located in the Sharizor Plain of Iraqi Kurdistan. Excavation of the mid to late 5th millennium BCE sequence at Gurga Chiya led to the discovery of an architectural complex with partially preserved pisé walls, most likely corresponding to a "tripartite" form of domestic building that appears widely characteristic of contemporaneous sites elsewhere in the Southwest Asia, from southeastern Turkey to central Iraq. One of the preserved rooms appears to have been used as a storage area for plant-based foods, as indicated by dense deposits of archaeobotanical remains, especially lentils and cereals. In this paper, we combine archaeological, architectural and archaeobotanical analysis to investigate the relationship between food storage and domestic economy at Gurga Chiya. These methods are supplemented by stable isotope analysis of $\Delta^{13}C$ and $\delta^{15}N$ values from preserved grains at Gurga Chiya and from the adjacent, Late Neolithic site Tepe Marani, and provides a diachronic perspective on changes in the methods used for cultivating crops. The limited data acquired from Tepe Marani and Gurga Chiya seem consistent with a gradual shift towards lower inputs per unit area – thus more extensive cultivation regimes – over time.

1. Introduction

Since the pioneering work of V. Gordon Childe in the 1930 s, the Neolithic domestication of plants and animals has been viewed as the economic foundation for the subsequent emergence of cities, kingdoms, and empires in Southwest Asia (Childe, 1936; Hesse 1994; Amy Bogaard et al. 2009; D. C. Haggis 2015; Scott 2017; D. Fuller and Stevens 2019). However, while the Neolithic origins of agriculture in this region are widely discussed (e.g. (Weiss et al., 2012; Bogaard, Bowles, and Fochesato 2019; Fuller, Denham, and Allaby 2023), the development of farming practices in the period between initial domestication and the rise of cities (between roughly 7000 and 4000 BCE) have received rather less attention. This is especially true of the 5th millennium BCE, corresponding to the Late 'Ubaid period in northern Mesopotamia, which witnessed key developments in village life that set the stage for the emergence of cities in the centuries that followed (Mccoriston 1997; Wengrow 2008; Algaze 2008; Sherratt 2011; McMahon 2020; Proctor, Smith, and Stein 2022). These changes are observable archaeologically in the spatial arrangements of individual dwellings, which attests to a new division of labor in domestic crafts and industries (e.g. textile and ceramic production; Wengrow 1998), as well as the storage of crop surplus in dedicated areas associated with large and increasingly

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independent households (Carter and Wengrow 2020). Such developments were accompanied by the introduction of new plant management strategies (e.g. animal tillage, expanding the acreage of arable fields, or additional irrigation) (Charles, Pessin, and Hald 2010; Fuller and Stevens 2019; Proctor, Smith, and Stein 2022). This paper tracks significant changes relating to agricultural production and food storage, based on archaeological and archaeobotanical material from the Late ʻUbaid period site of Gurga Chiya, in the Shahrizor region of Iraqi Kurdistan. Our aim is to contribute to ongoing discussion of agricultural development and the management of food surplus as interrelated factors, connected to the pivotal changes in Mesopotamian societies of the 5th millennium BCE.

2. Upscaling agriculture and surplus

Archaeologists have discussed the accumulation of crop surpluses in relation to novel strategies of food production, including both the intensification and extensification of arable farming practices (Sherratt 1999; Fuller and Stevens 2009). Intensification can occur through increased and recurrent labor input per land unit, employing methods such as tillage, shortening of fallow, soil fertilization by manuring, and irrigation, as well the selective sowing of crop species in habitats which best meet their biological requirements (Sherratt 1981; Fuller and Stevens 2009; Bogaard et al. 2013; Styring, Charles, and Fantone 2017). Extensification can be achieved through implementation of labor-saving techniques such as ploughing, especially through specialized plough animals, and by increasing the scale of agricultural land use (Styring, Charles, and Fantone 2017). Both strategies may have far-reaching environmental and social consequences (Ellis 2015; Fuller and Stevens 2017; Zeder, 2017).

It is widely accepted that in the arid regions of Southern Mesopotamia, farmers developed strategies of agricultural intensification aimed at increasing harvests and extending the range of arable land, based on irrigation systems and soil fertilization (Algaze 2008; Styring et al.2017). In the rainfed zones of northern Mesopotamia, where irrigation is not a requirement for the pursuit of agriculture, different strategies developed, favoring methods of extensification to increase the amount of land under cultivation, while reducing labor costs. These alternative strategies were attuned to the biological characteristics of domesticated plants, as well as factors of seasonality and soil properties that are particular to the dry-farming zone (Bogaard et al., 2018; Stroud, Bogaard, and Charles 2021; Styring, Charles, and Fantone 2017; Maltas et al. 2022).

The current state of knowledge indicates that generally during the Neolithic period land cultivation required more labor-intensive practices, such as manuring, performed on smaller areas (Bogaard et al. 2013; Styring et al. 2017), while the extensification of agricultural cultivation progressed over time. It has been argued that extensive farming, as it is characterized by increased areas under cultivation, heightened the significance of land owning, and fueled wealth accumulation, which constituted the foundation for further diversifications in the structure of society (Mulder et al. 2009; Styring, Charles, and Fantone 2017).

Surplus is one of the most notoriously debated phenomena in anthropology and archaeology of early societies (Sherratt 1999; Mintz and Du Bois 2002; Twiss 2012; Saitta 2016; Bogaard 2017; Hastorf and Foxhall 2017) It is a complex, multidimensional phenomenon, encompassing economic, biological, social, and psychological dimensions (Hastorf and Foxhall 2017). Surplus may be linked to a collective sense of security related to having enough food ensuring firstly survival, and then participation in culturally and socially conditioned activities such as gifting, feasting and reciprocity (Twiss 2012;Hastorf and Foxhall 2017). Or things may work the other way around, with the generation of surplus being driven primarily by social and cultural prerogatives – such as ritual or ceremonial feasting – rather than needs of subsistence (Hastorf and Foxhall 2017).

Overall, the role of food surplus in both Neolithic and post-Neolithic societies, practicing both intensification and extensification agricultural strategy served as a contingency strategy to cover the subsistence needs of the group, overcome potential seasonal shortages, and contributed to trade, exchange, or use as social currency (Kuijt 2009). It is often contrasted with the use of food surpluses as a tool of control and manipulation by elites, creating from top – down the realities of demand, which seems to be a general trend for example in Mesopotamian early states in later periods (Stein 2020).

Food storage is an activity aimed at protection of gathered or produced food surpluses from the weather conditions, as well as accumulating the foodstuff for extended periods of time, minimizing the food seasonality dependence (Lala and O'Brien 2010; Balbo 2015). For practical reasons, animal and plant products tend to be stored differently in pre-modern economies: long lasting plant products such as seeds, dried fruits or nuts tend to be stored within individual households, while perishable meats such as cattle or game used to be shared amongst households or neighborhoods (Bogaard et al. 2009).

Bogaard et al. (2009) have identified diachronic changes in food storage activities in Southwest Asia. Early evidence of plant-based food storage from PPNA sites includes remains of almonds from Hallan Çemi (Anatolia) and various accumulations of seeds, including barley and oats from Gilgal I (Southern Levant), where edible plants were stored in baskets (Weiss et al., 2006; Bogaard et al. 2009;). As sedentary life stabilizes and dependence on agriculture intensifies, the evidence for plant storage and surplus, including build-in structures such as clay bins of various forms, becomes more apparent, with notable examples from the Late Neolithic site of Sha'ar HaGolan (Southern Levant) (Twiss et al. 2004) as well as Neolithic Çatalhöyük (Central Anatolia) (Bogaard et al. 2009) and Tel Sabi Abyad (Northern Mesopotamia). Closer in time to the Lateʻ Ubaid settlement of Gurga Chiya, storage facilities are a common component of archaeological recovered buildings, as seen at Tel Abada (in northern Iraq) and Kenan Tepe (in south-east Turkey) (Carter and Wengrow 2020). Such evidence has been taken to illustrate a more general trend towards the storage of significant crop surplus in specific areas of houses or associated buildings (Graham 2011; Carter and Wengrow 2020). It may indicate that keeping surplus food within a household was such a common practice that storage facilities were included in the architecture of building structures.

3. Environment, landscape and archaeobotanical context of the Gurga Chiya site and its surroundings

The small site of Gurga Chiya, covering an area of approximately one hectare, is located on the Sharizor Plain, one of the most agriculturally fertile regions of Iraqi Kurdistan. The Sharizor Plain lies within the Mediterranean climate zone, receiving ca. 450–600 mm of rainfall per annum (Muehl 2012). Recent paleoenvironmental research (Altaweel et al. 2012; Marsh et al. 2018) made possible the detailed recognition of pre-modern developments in climate and landscape use, revealing complex vegetation surroundings of Late Ubaid (mid to late 5th millennium BCE) and Middle Uruk (mid to late 4th millenium BCE) Gurga Chiya and Late Neolithic neighboring site of Tepe Marani (mid to late 6th millennium BCE), where the marshy and grassy landscape was interspersed with forests and arable fields (Carter 2020). The sites lay southwest of the nearest city of Halabja, located by the foothills of Zagros mountains, and to the northwest lies an artificial lake of Darband-i Khan Dam Lake, established on the former headwaters of the Diyala River in the 1950 s, near the ancient site of Bakr Awa, which is by far the largest ancient settlement in the vicinity (Fig. 1.) (Miglus et al. 2011; 2013 after Carter et al. 2020). Tells of different sizes stretch eastward across the Shahrizor beyond Bakr Awa towards the highlands and westward up to the lake's edges, where the remains of ca. twenty villages from the early 20th century and an estimated seventy archaeological sites are now submerged (Wengrow et al. 2016).

Gurga Chiya, Tepe Marani, as well as nearby Tell Begum are situated

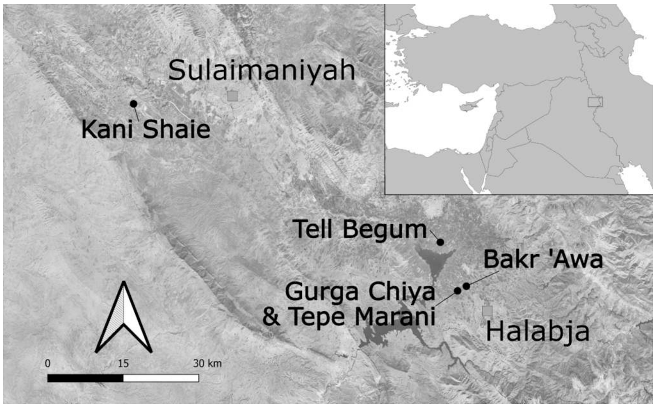

Fig. 1. Map with the location of Gurga Chiya and its vicinity. Created by J. Hordecki.

on Pleistocene terraces overlooking seasonal and perennial watercourses, which enables the development of arable farming practices. Recent years have seen a flurry of new archaeological investigation in the Sharizor Plain (Altaweel et al. 2012; Nieuwenhuyse et al 2016; Odaka et al. 2020; Odaka 2023) and adjacent regions of Iran (Hellwig 2023; Binandeh and Di Paolo 2023). The only Shahrizor site of comparable period to Tepe Marani is Tell Begum, from which archaeobotanical evidence has not yet been reported (Nieuwenhuyse et al. 2016; Odaka 2023), while much earlier Neolithic sites such as Bestansur and Jarmo to the west have reported evidence from the 8th and 7th millennia BCE (Matthews, 2016; González Carretero et al. 2023). Comparable archaeobotanical materials from the 'Ubaid and Uruk periods at Gurga Chiya are also found at the sites of Kani Shaie in the Bazian Basin, to the west of Sulaymaniyah (Renette et al., 2021; 2023) and Tell Abada (currently flooded by Lake Hamrin) (Jasim, 2021). The archaeobotanical material derived from Gurga Chiya is one of the largest assemblages from these phases in the Sharizor plain, and therefore the results reported here add a significant contribution to our knowledge of socio-economic use of plants in this area.

4. The archaeology of Gurga Chiya storage contexts

The archaeological and archaeobotanical material reported here come from the remains of a building with preserved *pisé* walls at Gurga Chiya, dated to the mid to late 5th millennium BCE., Late Ubaid period, with a major burning event occurring between 4460 and 4370 cal. BCE. (Carter and Wengrow 2020) (more details on the results of radiocarbon dating of these contexts are available in Supplementary Data file). Initial excavation of this building revealed that it was composed of at least four rooms (room 1 to 4), with doorways as connections between them and clay walls with stone foundations. Like the rest of the buildings the walls were made of *pisé* (rammed earth) with stone foundations below floor level, Further excavations led to the interpretation that Room 1 (Fig. 2) was used as a storage feature for plant foods. Most relevant are the samples recovered from a storage facility in Room 1. Room 1 measured around 2.4 × 1.80 m^2, with doorways at each end. It contained a badly damaged feature (context 336) which is interpreted as a burnt storage bin. Its precise original form and construction could not be ascertained; however it was visible the feature was formed from lumps of clay, perhaps representing the decomposed remains of a mudbrick structure. Its surviving remains showed a semi-circular shape abutting the western wall of the room. The central space of the collapsed feature was around 60–70 cm across, perhaps indicating the internal diameter of a cylindrical storage bin. The whole room was filled to a depth of up to 30 cm with a blackened deposit (context 334) rich in burnt seeds, nearly all lentils (Fig. 3). This deposit ran into Room 2 extending through the doorway and running up over the stone threshold between the rooms. Burnt lentils were also common in various other fills of the burnt house, suggesting that a violent conflagration had blown burning lentils throughout the building. (See Fig. 4. and Fig. 5.).

5. Materials and methods

5.1. Field sampling and flotation

Environmental sampling was carried out with the objective of recovering plant remains from most of the excavated features. Machine flotation was chosen method for the processing of the collected environmental samples. Bulk soil samples ranging from 1 to 10 L were processed, using meshes of 0.25 mm and 1.00 mm to catch the flot and residue respectively; details of the processed soil samples and volumes are summarized in the provided table (Table 1). The flots and residues were air dried and sorted by eye. All flots and sorted botanical materials from the residue were then identified using a low-powered binocular microscope.

5.2. Macrobotanical analysis

A total of 11 flotation samples were collected from Room 1 and Room 2 at Gurga Chiya (Fig. 2), all of which are included in this analysis.

Despite the low number of samples, these yielded an extremely high proportion of archaeobotanical remains with a total number of 30.300 seeds, seed fragments and food remains. The totality of plant remains recovered from the flots such as seeds, nuts, fruits and chaff were identified using modern seed reference collections housed at the UCL Institute of Archaeology. Classification was based on seed atlases (Anderberg 1994; Cappers and Bekker 2006; Cappers et al. 2012), archaeobotanical publications (Jacomet and Greig 2006; Jones 2005), open access repositories such as Digital Plant Atlas (https://www.plantatlas.eu/), and comparison with reference collection materials. Once identified to genus level, lists of geographically relevant species were extracted from Flora of Iraq (Guest et al. 1966). Macrobotanical remains were identified using a low-powered binocular microscope (x10–60) and the nomenclature generallyfollowed Flora of Iraq (Guest et al. 1966). The abundance and full counts as well as diversity of plant macrofossils were recorded using an excel database.

5.3. Stable isotopes analysis

Recently, research into ancient cultivation practices has significantly advanced, driven by developments in stable nitrogen (δ^{15}N) and carbon (δ^{13}C) isotope analysis of preserved archaeobotanical remains (Fiorentino et al. 2014; Wallace et al., 2013; Styring, Charles, and Fantone 2017). These advancements have provided more detailed insights into past plant growth conditions, enabling inferences about ancient cultivation methods, and serving as a cognitive tool in examining past cultivation practices in this study.

Stable isotope analyses were carried out at the Stable Isotope Laboratory of the Max Planck Institute of Geonathropology, Jena, Germany. A total number of 11 contexts have been selected for isotopic measurements of δ^{13}C and δ^{15}N values from Late Ubaid levels from Gurga Chiya, in addition to 3 contexts selected from Late Neolithic levels of Tepe Marani (Table 1). The samples were decided based on the archaeological contexts (as described above), while individual grains were selected based on their visual characteristics, following the criteria for choosing optimal grains for isotopic analysis outlined by Stroud et al. (2023). The size of the selected sample was determined by three key factors: the availability of archaeobotanical data, the suitability of the archaeological context, and the potential to compare the selected specimens with previously published studies from stable isotopes analysis performed on plants from archaeological contexts. Additionally, the site of Tepe Marani site was selected for comparative analysis due to its immediate proximity to the Gurga Chiya site and its comparable data set

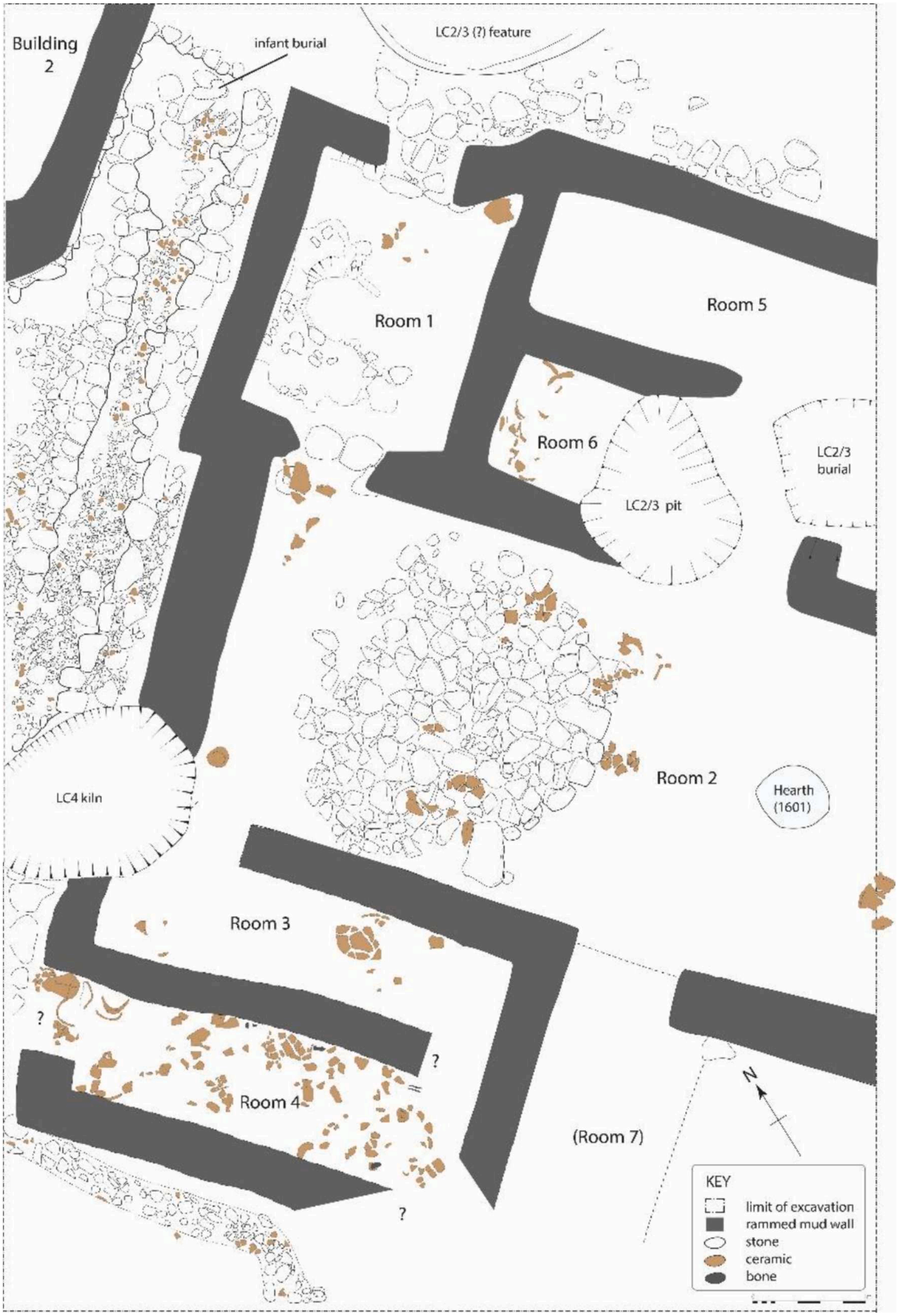

Fig. 2. Plan of the site with discussed contexts, by R. Carter.

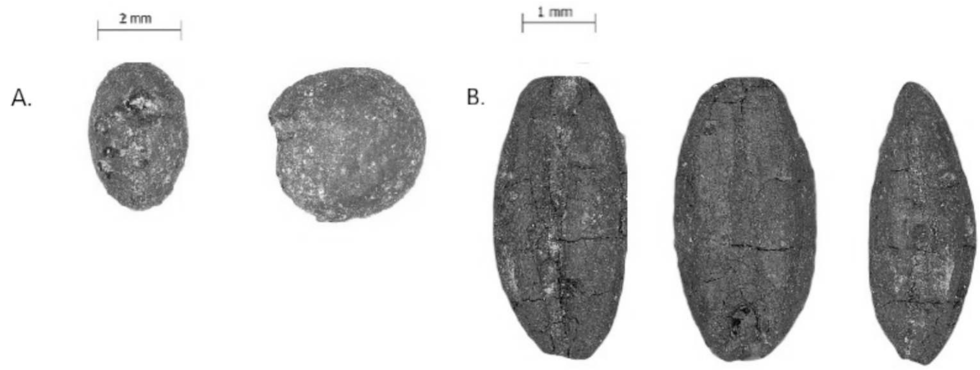

Fig. 3. Dominant archaeobotanical crop remains from storage contexts of Gurga Chiya; A) Lentil B) Barley.

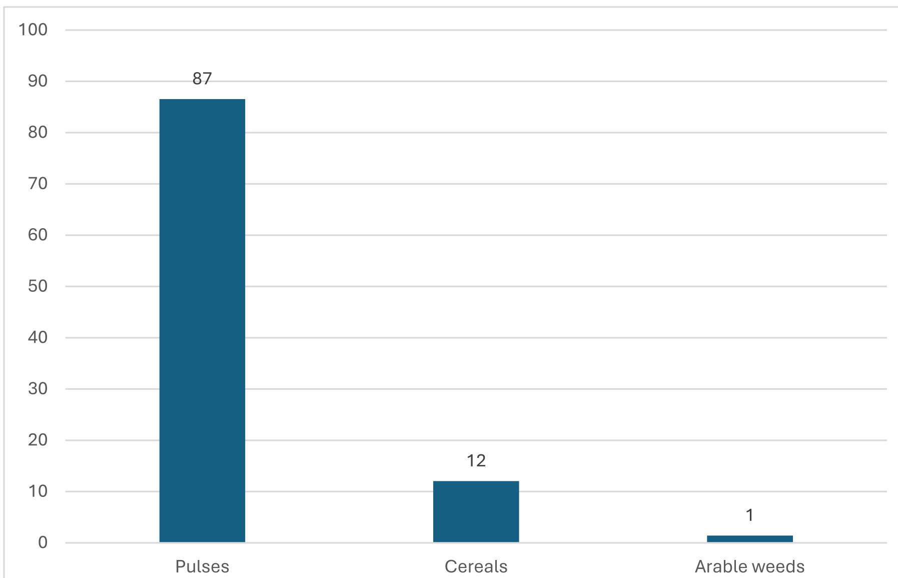

Fig. 4. Macrobotanical assemblage from the discussed contexts, categorized into three general categories.

(except of lentil), which provides interesting insight into the changing growth conditions of the same plant species over time.

Charred remains of three different crop species were analyzed: Emmer (*Triticum dicoccum* L.) (4 seeds), barley (*Hordeum vulgare* L.) (7 seeds) and lentil (*Lens culinaris* L.) (8 seeds). Due to the generally low number of wheat grains in the archaeobotanical assemblages, only 5 % of the selected grains from both sites were checked to determine carbonate, nitrate and/or humic contamination and therefore the need for pre-treatment. The grains were analysed through Fourier Transform Infrared Spectroscopy (FTIR) Bruker Vertex 70v to collect IR spectra using Attenuated Total Reflectance (ATR). The values of samples were measured, and the background noise subtracted to assist in the recognition of contamination by carbonates, humic acid and nitrates (following Vaiglova et al. 2014). It was observed that no contamination was present in Tepe Marani samples. Therefore, to reduce mass loss it was decided to not perform any further chemical pre-treatment. However, the detection of a slight peak characteristic of carbonate and nitrate contamination in grains from Gurga Chiya led to acid pre-treatment of all Gurga Chiya samples. The pre-treatment procedure was consisted of washing the crushed samples in treatment in aqueous 0.5 MHCl at 80 °C for 30 min followed by three rinses in ultra-pure water (Vaiglova et al. 2014). The samples were analysed on a Thermo Fisher Scientific Flash Elemental Analyzer coupled to a Thermo Fisher Scientific Delta V Isotope Ratio Mass Spectrometer via a ConFloIV system. A two-point calibration was performed using international standard reference materials USGS40 (δ13C = −26.4 ‰±0.04 ‰, δ15N = −4.5 ‰ ±0.1 ‰), IAEA N2 (δ15Ntrue = 20.3 ‰±0.2 ‰) and IAEA C6, (δ13C = −10.5 ‰±0.0 ‰). USGS61 (δ13C = −35.05 ‰±0.04 ‰, δ15N = −2.87 ‰±0.04 ‰) and UREA (δ13C = −41.3 ‰, δ15N = −0.32 ‰). Replicate analyses of the analytical standards suggest that machine measurement error is c. ± 0.37 ‰ for δ^{13}C and ± 0.37 ‰ for δ^{15} N. The δ^{13} C and δ^{15} N values were adjusted to account for the effect of charring by subtracting 0.11 ‰ and 0.31 ‰ following Nitsch et al. (2015). The Δ^{13}C values (the difference in the ratio of stable carbon isotope (^{13}C and ^{12}C) of the cereal grains were calculated to allow comparison with modern data, following the Farquhar et al. (1982). The approximated δ^{13}C value of atmospheric CO2 (δ^{13}Cair) was obtained from reference tables (Ferrio et al., 2005), and calculated using the cal. BCE date range of each site. All δ ^{13}C values were converted to Δ^{13}C using the Farquhar et al. (1989) equasion:

$$\Delta^{13}C = \frac{\delta^{13}C_{air} - \delta^{13}C_{plant}}{1 + \delta^{13}C_{plant}/1000}$$

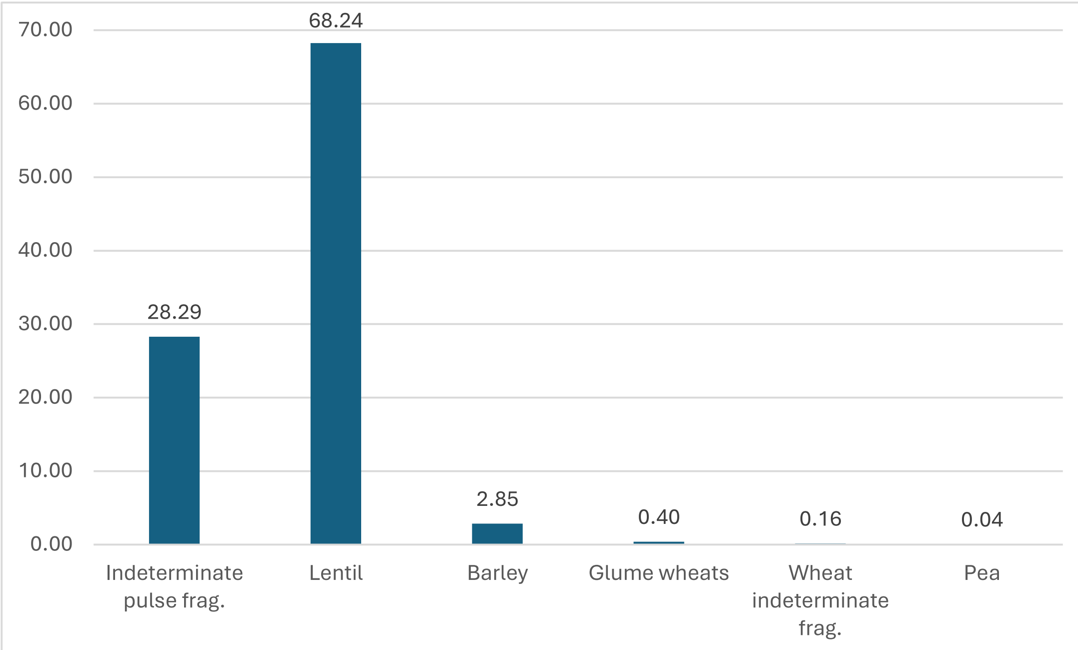

Fig. 5. Breakdown of cultivated food crops.

Table 1
Table presenting plant seed specimens analyzed for $\delta^{13}C$ and $\delta^{15}N$ stable isotopes composition analysis.

Site	Context nr	Context description	Sample	Species	Phase
Gurga Chiya	1621	Domestic	14064	lentil	Ubaid
Gurga Chiya	1631	Domestic	14063	barley, lentil	Ubaid
Gurga Chiya	1600	Domestic	14061	lentil	Ubaid
Gurga Chiya	1595	Domestic	14060	lentil	Ubaid
Gurga Chiya	1630	Domestic	14057	lentil	Ubaid
Gurga Chiya	1620	Domestic	14052	lentil	Ubaid
Gurga Chiya	1602	Domestic	14050	lentil	Ubaid
Gurga Chiya	1596	Domestic	14048	barley	Ubaid
Gurga Chiya	1541	Domestic	14036	lentil	Ubaid
Gurga Chiya	334	Domestic	14027	barley, emmer wheat, lentil	Ubaid
Gurga Chiya	328	Domestic	14024	barley, emmer wheat	Ubaid
Tepe Marani	5012	Domestic	13031	barley, emmer wheat.	Late Neolithic
Tepe Marani	5012	Domestic	13029	barley	Late Neolithic
Tepe Marani	6002	Domestic	13001	barley, emmer wheat	Late Neolithic

6. Results

6.1. Macrobotanical analysis

A. *Gurga Chiya*

The archaeobotanical assemblage of Gurga Chiya is largely represented by pulses (87 %), followed by cereals (12 %), and trace amounts of arable weeds (ca. 1 %). The extremely high number of whole and fragmented lentils (*Lens culinaris* L.) found (n = 19557) indicates the importance of lentils as a major crop at Gurga Chiya. Amongst the pulses, there were also a minor presence of other legumes including domesticated pea (*Pisum sativum* L.) (n = 7) and wild grass pea (*Lathyrus sativus* L.) (n = 5), as well as over (n = 8010) fragments of indeterminate large legume fragments (Fabaceae). Among the cereals, the highest ubiquity corresponds to indeterminate cereal fragments (n = 1717). It is followed by barley grains (*Hordeum vulgare* L.) (804 grains and grain fragments) of the hulled variety (802), with a single grain of barley indeterminate, and a further one identified as naked barley (*Hordeum vulgare* L. var. *nudum*). The presence of that of wheat species (*Triticum* spp.) is remarkably low, especially when compared to remains of barley, summing up to 112 emmer grains and grain fragments (*Triticum dicoccum* L.), and 5 einkorn grains (*Triticum monococcum* L.). In contrast with the abundant concentration of cereal grains and legume seeds, virtually no chaff was present in the analysed samples, with only a single emmer glume base identified. Among the weeds, the most ubiquitous are seeds of cow cockle (*Gypsophila vaccaria* L.), ryegrass (*Lolium* spp.), and a common species of wild mustard (*Descurainia sophia* L.). The reported assemblage suggests that the contexts where this assemblage was found were facilities dedicated to store large quantities of crops, particularly lentils.

B. *Tepe Marani*

Combined general trends for the domestic contexts of Late Neolithic Tepe Marani show the slightdomination of pulses (38 %) over cereals (28 %) amongst edible plants. In addition, a total of 31 % of the entire assemblage are various species of wild seeds, with their majority belonged to arable weeds. A generally high incidence of chaff was noted (n = 131), compared with grains (152). Five major crop taxa have been identified: most commonly recorded were lentils (*Lens culinaris L.*) and common vetch (*Vicia sativa L.*), barley (*Hordeum vulgare L.*), and wheat (*Triticum* spp.*)*. Both emmer (*Triticum dicoccum*) and einkorn (*Triticum mononoccum*) were found, yet due to general poor preservation of

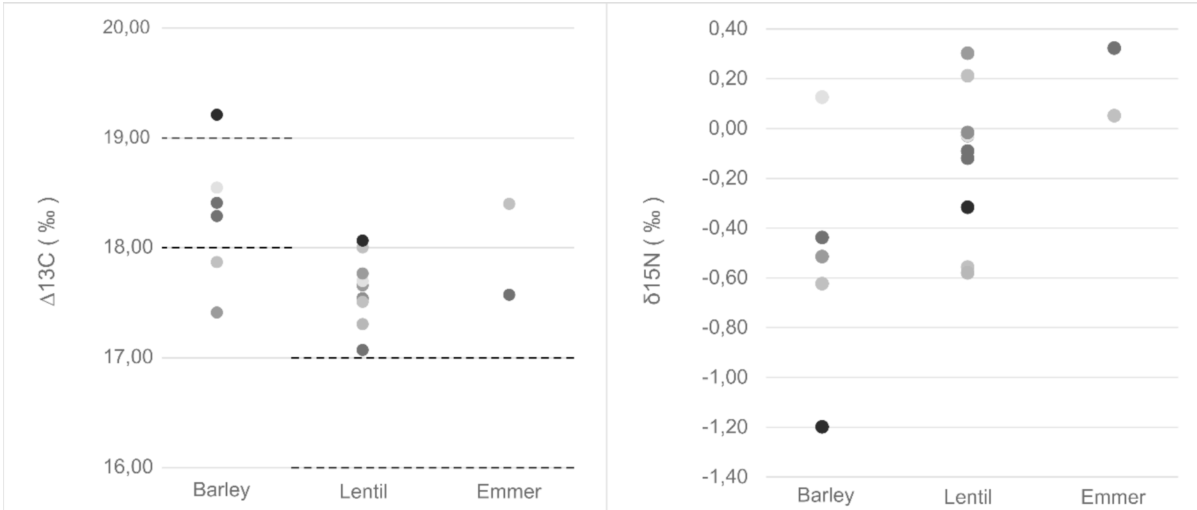

Fig. 6. Presents $\delta^{15}N$ and $\Delta^{13}C$ values of archaeobotanical grains from Gurga Chiya. Dashed lines indicating bands between crops grown under poor (low values), moderate and high (high values) water availability ($\Delta^{13}C$) based on analysis of modern crops presented in Wallace et al. (2013).

archaeobotanical remains, yet their preservation was generally poor.

6.2. *Stable isotopes analysis of Late Ubaid Gurga Chiya and Late Halaf Tepe Marani contexts*

Fig. 6 compares crop $\Delta^{13}C$ values from Gurga Chiya's Ubaid levels with modern ranges of Δ13C values for crops grown under different watering conditions, as defined by Wallace et al., 2013. Barley $\Delta^{13}C$ values suggest moderate to well-watered conditions, averaging 18.2 ‰, within the documented variability range of 1 ‰ for crops under similar conditions. Barley is inherently more drought-tolerant than wheat (Stroud et al., 2021; Bogaard et al., 2013), and its $\Delta^{13}C$ values imply it was indeed grown under slightly drier conditions compared to glume wheat, which reflects a strong well-watered signal. However, the small sample size must be noted.

For lentils, the $\Delta^{13}C$ values, including those from storage contexts, align with Wallace et al., 2013 range for well-watered crops. Experiments conducted on modern plants indicate that legumes have higher water sensitivity than cereals – they tend to appear wetter in 'wet' environments and 'drier' in dry environments (Wallace et al., 2013). $\Delta^{13}C$ values of lentil seeds are higher (average 17.6 ‰, when the potential 1 ‰ difference between species is taken into account) than those measured on barley grains, suggesting that they were cultivated on the soils with better water access during cultivation.

The $\delta^{15}N$ values for cereals are generally low (<0.5 ‰) and align with reference values indicative of no manuring (Fraser et al., 2011). Barley $\delta^{15}N$ exhibits notable variability, ranging from −1.2 ‰ to 0.1 ‰, which is consistent with the $\Delta^{13}C$ results. As confirmed by several experimental and archaeological studies (e.g., Farquhar et al., 1982; Farquhar and Richards, 1984; Wallace et al., 2013; Bogaard et al., 2016; Styring et al., 2017; Stroud et al., 2021; Maltas et al., 2022), there is a negative relationship between high rainfall and grain $\delta^{15}N$ values. This relationship likely explains the trends observed in the barley data. The results for glume wheat show a similar pattern.

The $\delta^{15}N$ values from lentils show a range of −0.58 ‰ to −0.37 ‰ with most samples falling below 0 ‰. Current knowledge indicates that $\delta^{15}N$ values of pulses are heavily affected by fixation of atmospheric nitrogen (Fraser et al. 2011). According to Fraser et al. (2011) low level manuring with high water access elevates the $\delta^{15}N$ values of pulses within the range of measurement error, making them indistinguishable from unmanured values. Therefore, it is not possible to definitively determine the manuring status of the Gurga Chiya lentils.

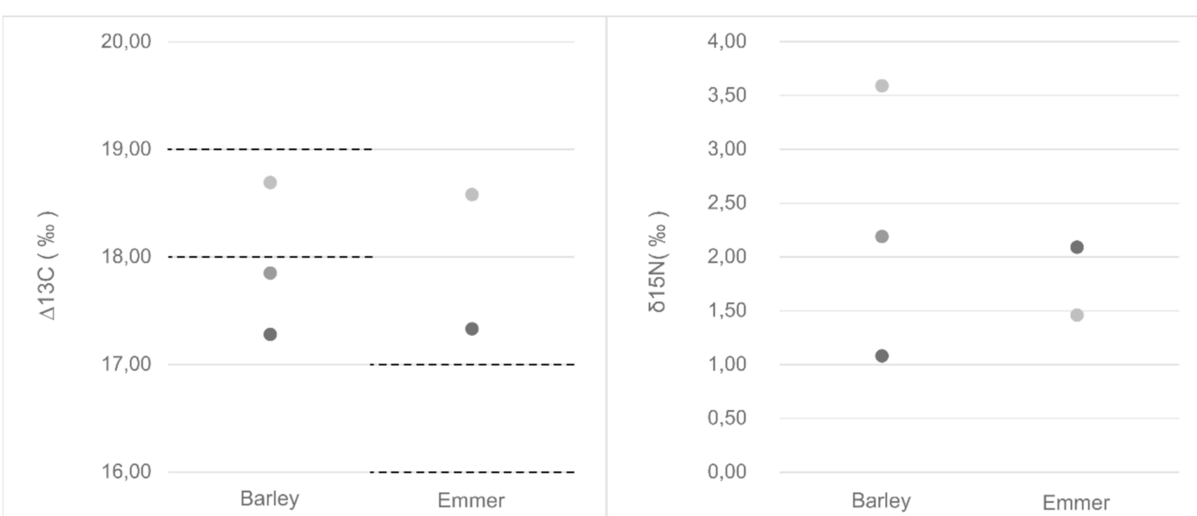

Fig. 7. Presents $\delta^{15}N$ and $\Delta^{13}C$ values of archaeobotanical grains from Tepe Marani. Dashed lines indicating bands between crops grown under poor (low values), moderate and high (high values) water availability ($\Delta^{13}C$) based on analysis of modern crops presented in Wallace et al. (2013).

Although the comparison between phases is limited by low sample number as well as poor preservation of Tepe Maranis' archaeobotanical remains, our data still provides a further source of information for studying Late Neolithic cereal cultivation in the region. The presented Δ^{13}C values of barley crops from Late Neolithic (Late Halaf) Tepe Marani (Fig. 7) indicate poor to moderate watering, while values for emmer wheat are consistent with very high-water availability. This may suggest that drought-resistant barley was cultivated on drier soils than the more water demanding emmer wheat, as would be expected (Masi et al. 2014; Riehl et al. 2014; Wallace et al. 2014).

The δ^{15}N values for both species are higher than those from the chronologically later Gurga Chiya, yet still within the range of no/low to moderate manuring (Fraser et al.2011). The variability presented within the results (especially for barley grains) may document the effect of non-consistent, low intensity manuring along with moderate watering, yet as previously stated, further conclusions are limited due to the low number of samples.

7. Discussion and conclusion

The stable isotopes data presented allows us to shed light on growing conditions, which apply to three of the most ubiquitous crops from Late 'Ubaid Gurga Chiya: lentil, barley and emmer wheat. The stable isotope analysis results of Δ^{13}C values suggest that barley was cultivated in slightly drier conditions than wheat, yet further comparison with Δ^{13}C results on wheat species is necessary to determine this accurately. Cultivating barley on drier soils than those for glume wheats is flagged as an indicator of planned management strategies, based on taking advantage of barley's biological properties such as higher drought tolerance (Riehl et al. 2009). This practice has been observed in number of Northern Mesopotamian sites, namely 'Ubaid-period Tell Zeidan and Tell Brak (Styring et al. 2017), as well as Anatolian Chalcolithic sites such as central Anatolian Çamlıbel Tarlası and Çatalhöyük West (Stroud et al. 2021) and western Anatolian Liman Tepe and Bakla Tepe (Maltas et al. 2022). The diverse landscape of Gurga Chiya and Tepe Marani consisted of rivers, riparian woodlands and grasslands (Carter et al. 2020) providing a mosaic of wetter and drier areas. Isotopic analysis confirms that, as might be expected, the inhabitants of this region were selecting specific plots of farmland for cultivation, based on the particular biological requirements of sown plants. The diversity within Δ^{13}C for different crops represented in Gurga Chiya and Tepe Marani illustrates a difference in slope within the fields, ranging from drier hilltops to the wetter valley-bottoms (cf. Stroud et al. 2021). It seems that arable fields for Gurga Chiya's staple crops were not fertilized by spreading manure or grazing, which is consistent with the view that livestock were not incorporated into practices of field rotation.

Tepe Marani's stable isotopes analysis results for crops show a different pattern, where the obtained values can be interpreted as an effect of soil fertilization – probably associated with seasonal animal grazing, as part of the cropland rotation. Although the data is limited, the combined results from Late Halaf Tepe Marani and Late 'Ubaid Gurga Chiya point to the inhabitants of these settlements using similar methods to optimize access to water, based on selective sowing of cereals in places that meet their biological needs. The results of δ^{15}N stable isotope analysis, however, indicate the decrease over time in rates of soil fertilization. Hypothetically, this could indicate the use of extensification methods, such as increasing the area of crop fields and excluding livestock from the land use plan (Styring, Charles, and Fantone 2017; E. Stroud 2016).

The limited data acquired from Tepe Marani and Gurga Chiya seem consistent with a gradual shift towards lower inputs per unit area – thus more extensive cultivation regimes – over time (cf. Diffey et al. 2020; Styring, Charles, and Fantone 2017). This sequence of developments is visible mainly through comparison of better-studied models of late Neolithic intensive cultivation and early historic examples of extensification (Styring, Charles, and Fantone 2017; Maltas et al. 2022; Diffey et al. 2020). Any firm conclusionsregarding the position of the 'Ubaid period within these wider transformations must await the accumulation of further data from contemporaneous sites to supplement what is still an extremely patchy record of environmental change in the 5th millennium BCE. Nevertheless, we might venture some tentative observations, arising from the data presented here, as well as recent critiques of social evolutionary models, as applied to the Late 'Ubaid period in general.

It has often been assumed, for example, that evidence for the specialized storage of economic surplus must be linked to the growth of social stratification, and the emergence of elites, manipulating such surpluses to their own advantage (for various perspectives, see: Frangipane 2007; Algaze 2008; Stein 2020). The 'Ubaid period, in particular, has often been considered to mark an evolutionary "steppingstone" from egalitarian villages of the later Neolithic to emergent processes of state formation and social hierarchy, via the emergence of "chiefdoms" (e.g. Stein 1994; Algaze 2008; for an early critique, see Yoffee, 1993). From an archaeological perspective, the first markers of this shift are often considered to be differences in the sizes and inventories of domestic dwellings, as well as establishment of two-tier settlement hierarchies, with smaller villages distributed around central settlements (Carter et al., 2010; Smith et al., 2015). Stein (2020) interprets the extensive 'Ubaid household from the site of Abada (Syria) – *House A* – as an example of the socio-economic diversity prevailing among the inhabitants of a Chalcolithic village. *House A* intergenerationally remained the largest dwelling, serving as an example to support the theory that wealth disparities were being passed down, and started to take on the form of social ranking (Stein 2020). Another frequently mentioned aspect of social evolutionary theory is control over food surpluses, understood as a form of wealth, which could be potentially used by the 'Ubaid elites to transform this economic advantage into centralized, and later formalized, political power (Stein 1998).

However, evidence for communal food storage at earlier sites of the Late Neolithic (Halaf) period in northern Mesopotamia – such as Tell Sabi Abyad (Akkermans and Duistermaat 1996) and Yarim Tepe II (Merpert and Munchaev, 1993) – serves to complicate the proposed relationship between food surplus and social inequality (Wengrow 1998). Frangipane (2007), for example, argues that such evidence points instead to the horizontal distribution of surpluses among the wider community, as opposed to within ranked households or lineages. Others have related practices of specialized storage to the practice of transhumant pastoralism, whereby a part of the village population is obliged to relocate with their herds for a significant part of the year, necessitating more complex patterns of storage and redistribution of property (Akkermans and Duistermaat 1996). Graeber and Wengrow, in *Dawn of Everything* (Graeber et al., 2021, pp. 421–429), take a different approach again. Based on comparisons with the workings of egalitarian systems elsewhere, they note that the appearance within late Neolithic Mesopotamian villages of specialized storage facilities and proto-bureaucratic methods of recording (e.g. seals and sealing archives) may in fact relate to the suppression of social inequalities, by promoting the equitable division and distribution of resources within small, face-to-face communities. Archaeologically attested devices for controlling access to stored surplus, such as door and vessel sealings, as well as administrative tools (numerical tokens and seals), may have initially been invented to facilitate the fair distribution of the stored goods, and were only much later adapted to become instruments of exclusion, private wealth accumulation, and social control (Graeber and Wengrow 2021). Against this backdrop, the movement of crop storage facilities out of public or communal areas and directly into the space of extended households undoubtedly represents a significant development (cf. Frangipane 2007; Akkermans and Schwartz 2004).

At the Late 'Ubaid site of Gurga Chiya, there is clear evidence for the storage of agricultural crops in quantities which exceed the basic needs of a single household, potentially enabling reciprocal activities and exchange. In particular, the amounts of lentils recorded, especially in comparison to that of cereals, might be explained by the abundance of certain crops during specific seasons, and/or the varied ways that different plant resources are used in cooking, such as wheat being used to make porridge or bread (Carter et al. 2020). The storage contexts are interpreted as belonging to an individual domestic unit, which would imply an increasing degree of economic autonomy for large households (Carter and Wengrow 2020). An absence of processing waste in associated deposits, such as pods and chaff, suggests that crop processing took place before storage, and possibly outside the building, a pattern that is also found in other sites of the 'Ubaid, such as Tell Abada and Kenan Tepe (Jasim 2021; Graham 2011; Graham and Smith 2015). Such activities would have required the involvement of a large number of people – which may indicate reciprocal arrangements among village units, but also the existence of large, multigenerational families, engaged in seasonal cooperation for harvesting activities (Fuller and Stevens 2009). A further indication of the growing economic autonomy of individual households in the 'Ubaid period may be the general absence of evidence for administrative control of surpluses, of the kind found both in earlier (Late Neolithic) and later (Chalcolithic/Early Bronze Age) contexts (Frangipane 2007; Akkerman and Duistermaat 2004).

To conclude, the excavations at Gurga Chiya are yet limited to the exposure of approximately half of a single extended household in a site of roughly one hectare in size; hence any conclusions arising from this material must remain extremely tentative. Nevertheless, such evidence as does exist seems consistent with a wider pattern, observed at other sites of the Late 'Ubaid period, where the appearance of specialized storage areas for crops and other goods within the physical framework of individual households replaces an earlier pattern of communal storage and management between households. How, exactly, this shift in the spatial locus of agricultural storage relates to wider patterns of social and political change remains far from clear. While extended households may have achieved greater levels of economic autonomy within the context of settlements, during the Late 'Ubaid period, this need not imply any kind of formal ranking or hierarchy among households or families. Indeed, such developments may equally reflect new patterns of interdependence *between* households at the inter-site level, including coordinated exchanges of crop surpluses. This, in turn, may have permitted the growth of agricultural specialization at a local scale, reflecting the different affordances of particular crops and micro-environments, as reflected in the archaeobotanical data of Gurga Chiya.

CRediT authorship contribution statement

Karolina Joka: Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Investigation, Conceptualization. **Lara González Carretero:** Formal analysis, Writing – review & editing. **Dorian Q Fuller:** Supervision. **Patrick Roberts:** Resources. **Robert Carter:** Writing – review & editing, Supervision, Project administration. **David Wengrow:** Writing – review & editing, Supervision, Project administration.

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.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2025.105093.

Data availability

Data will be made available on request.

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