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Plant Cultivation and Commodification in the Chalcolithic and Early Bronze Age of Southwest Asia and their Cultural Significance. The case of Late Ubaid Gurga Chiya (Iraqi Kurdistan), Early Bronze Age Kani Shaie (Iraqi Kurdistan), and Early Bronze Age Tel Qedesh (Israel)

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Dziękuję!

Thank you!

[1] or at least in an unchanged degree of madness

Spis treści

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Major thesis of the PhD dissertation

1. Introduction

The domestication of plants, and the subsequent emergence of agriculture, is one of the determinants of the Neolithic revolution, and which triggered a series of economic and social changes (e.g Miller 2000; Boivin, Zeder, and Fuller 2016). Agriculture had an impact on the landscape (arable fields, deforestation), society (sedentism, crop storage) and ecology (domestication of plants and animals) (Dorian Fuller and Stevens 2019). One of the effects of farming was the increase in population, which was associated with the emergence of non-agricultural specializations and extensive forms of distribution of goods and trade (Scott 2017)

In the Southwest Asia, the offset between the emergence of agriculture, organised form of the arable fields, and the first cities is significant, and amounts to ca. 5000 years (Boivin, Zeder, and Fuller 2016). It is generally agreed (Sherratt 1999; Fuller and Stevens 2019;Fuller and Stevens 2009; Frangipane 2018) that during this period perennial plants (such as olive, grape, fig, pomegranate and date) were cultivated and then domesticated (Fuks et al. 2020; Langgut 2024; Joka et al. 2024) forming the foundations for the subsequent development of the so– called "cash crops", whereas cereal cultivation has undergone numerous transformations aimed at more efficient harvests (Bogaard et al. 2013; 2017; Stroud, Bogaard, and Charles 2021; A. K. Styring et al. 2022). Both categories, as well as plants' secondary products (e.g. wine, oil, dried fruits) have also undergone commodification processes, becoming goods on the sales market.

While the first steps have been extensively studied, the latter process remains largely under researched. My PhD research project pertains to the third step in the process outlined above has three intertwined objectives:

1. The recognition of the process and mechanisms of plant commodification and its culture-forming impact, especially for the emergence of increased social complexity in Northern Mesopotamia

2. The recognition of the process and mechanisms of the emergence of new agricultural practices, including intensification and extensification methods, the introduction of new crops—particularly perennial plants. Furthermore, the enduring impact of the advanced agricultural processes, including deliberate practices of delayed returns, and its far-reaching consequences for increased social complexity in Southwest Asia.
3. the applicability of using stable isotope analysis results on archaeobotanical material as a heuristically viable tool for recognizing the processes of commodification.

The study covers the period from 5th to the beginning of the 3rd millennium BCE, which covers the emergence of advanced farming and related practices in Southwest Asia. From the culture-historical standpoint, this covers a period between Late Neolithic and Early Bronze Age. The advocated objectives will be achieved by comprehensive study of botanical and archaeological materials from three sites from the studied region:

(i) Gurga Chiya, Iraqi Kurdistan – Late Chalcolithic

(ii) Kani Shaie, Iraqi Kurdistan – Early Bronze Age

(iii) Tel Qedesh, Israel - Early Bronze Age II

The results of my study were published in three articles in highly established peer-reviewed journals. All of them are on the A list of the Ministry of Science and Higher Education, and each publication covers a different issue related to the broadly understood topic of commodification processes of agricultural crops.

The first paper *Exploring the potential of stable carbon and nitrogen isotope analysis of perennial plants from archaeological sites: A case study of olive pits and grape pips from Early Bronze Age Qedesh in the Galilee* (Joka et al. 2024) focuses on the applicability of stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope analysis to olive and grape remains to recognize the past cultivation methods. Olives and grapes were among the first and most popular fruit cultivars (Early Chalcolithic) and commodities (by Early Bronze Age), however, the cultivation practices used to manage these crops remain poorly understood prior to evidence from the historical record. This paper then is attempting to bridge the knowledge gap in recognition of past cultivation of abovementioned fruit plants by engaging – for the first time – the SIA towards perennial plants from archaeological contexts. The presented work summarizes the research on the cultivation of perennial plants from archaeological and historical sources, and signalizes the potential methodological issues connected to the application of the SIA of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$). Based on the results of the set of experiments, a comprehensive protocol was established to develop a methodological framework and interpretative model for perennial plants, building on models previously used for studying cereals and pulses. Finally, the application of these methods made possible to recognize that Early Bronze Age II olives from the Tel Qedesh site in the Upper Galilee were characterized by a high degree of hydration at the time of growth.

The second article, *Plant Commodification in Northern Mesopotamia: Evidence from the Early Bronze Age Site of Kani Shaie, Iraqi Kurdistan* (Joka 2025) is presenting the new evidence on the presence of early distribution and commodification of agricultural surplus in a small-scale Early Bronze Age (EBA) community at Kani Shaie in the Bazyan Valley, Iraqi Kurdistan. Archaeobotanical (cereal and pulses) and archaeological (sealings) findings from an architectural complex dated to the early EBA indicate that it served as a food storage and redistribution hub. Kani Shaie's strategic location at the crossroads of the Zagros Mountains and Mesopotamian lowlands highlights its role in mobility networks connecting plains and highlands. This research sheds light on the significance of small, remote administrative centers in plant resource commodification, both prior to and beyond major urbanized centers.

The article *Storage story: investigating food surplus and agricultural methods in Late Ubaid Gurga Chiya (Iraqi Kurdistan)* explores agricultural practices and societal developments during the Late Ubaid period (5th millennium BCE) in northern Mesopotamia, with a focus on the site of Gurga Chiya in Iraqi Kurdistan. This paper combines archaeological, architectural and archaeobotanical analysis to investigate the relationship between plant food storage and domestic economy at Gurga Chiya and it examines how these practices contributed and reflected the broader social and economic transformations. Evidence at Gurga Chiya shows storage of surplus crops, particularly lentils, exceeding the needs of single households, suggesting reciprocal exchanges or economic autonomy of large, multigenerational households. Such a movement of crop storage from communal spaces to individual households signals increased household autonomy but does not necessarily imply formal social hierarchies. The spatial and archaeobotanical analysis are supplemented by stable isotopes analysis (henceforth SIA) of $\Delta^{13}C$ and $\delta^{15}N$ values from preserved grains at Gurga Chiya and from the adjacent, Late Neolithic site Tepe Marani. This, in turn, provides a diachronic perspective on changes in the methods used for cultivating crops, suggesting that over time agricultural practices shifted from intensive cultivation to more extensive methods.

2. Conceptual and theoretical framework

The key concept to this PhD dissertation is commodification of plant resources (cereals and perennials), in particular its emergence, development, and long-lasting significance within the context of past economies and agricultural developments prior to the emergence of first cities.

The commodification is understood in this work as the process of attributing value to resources—such as agricultural crops processed for storage or exchange, raw materials transformed into artifacts, natural resources (e.g., water, stone, wood) or real estate (e.g., coastlines, farmland, and structures). The process reaches its apex when the resource is *marked* as a commodity and exchanged for an equivalent value. However, whether a resource becomes a commodity depends on its social context, which can differ across the groups and individuals (Kopytoff 1986).

In the period between Late Neolithic and Early Bronze Age in Southwest Asia, both annual cultivars (cereals and pulses) and perennials have undergone the commodification processes and became products with fixed exchange value. The subsistence plants such as cereals and pulses gained their value through bulking, while the perennial plants, such as olive, grapevine, figs etc. increased in value through transformation into secondary products such as olive oil, wine, and dried fruits. Most notably, in Southwest Asia, the cultivation and later commodification of perennials, a major part of the process of social and economic diversification in the Bronze Age, ultimately led to the emergence of *investment agriculture* and *cash crops,* which were argued to have been one of the pillars of early urban economies. *Investment agriculture* phenomenon is a form of land use relied on longer term labor input with an acceptance of prolonged period of growth before harvest and profiting, and as such have been argued to have acted as a trigger for the development of land ownership rights and social stratification (Renfrew 1972; Sherratt, 1999) . *Cash crops* are the species that do not directly contribute towards subsistence, either because they are produced for craftsmanship or for trade (Sherratt 1999).

The process of commodification is inevitable connected to the food surpluses, an economic reality, which arose with development of agricultural societies, and led to the formation of non – farming specialists, causing the emergence and development of such professions as metallurgy, textile production, administration and trade. Surplus is one of the most widely debated topics in the anthropology and archaeology of early societies (Bogaard et al. 2017; Hastorf and Foxhall 2017; Saitta 2016; Sherratt 1999). As Hastorf and Foxhall highlight in *The Social and Political Aspects of Food Surplus* (2017), surplus extends beyond economics, encompassing biological, social, and psychological dimensions. Food surplus may be associated with a collective sense of security, ensuring survival while enabling participation in culturally and socially significant practices such as gifting, feasting, and reciprocal exchanges (Hastorf and Foxhall 2017). Alternatively, the production of surplus might be primarily driven by social and cultural imperatives—such as ceremonial or ritual feasting—rather than solely by the demands of subsistence.

Archaeologists have also discussed the accumulation of crop surpluses and commodification 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 involves increasing and sustaining labor input per unit of land through methods such as tillage, reduced fallow periods, soil enrichment via manuring, irrigation, and the strategic sowing of crops in habitats that best suit their biological needs (Sherratt 1981; Fuller and Stevens 2009; Styring, Charles, and Fantone 2017; Bogaard et al. 2013). In contrast, extensification focuses on expanding agricultural land use by employing labor-saving techniques, such as ploughing, and scaling up the area under cultivation. Current research suggests that during the Neolithic period, land cultivation typically relied on labor-intensive practices such as manuring and plowing, often carried out on smaller plots of land (Styring, Charles, and Fantone 2017; Bogaard et al. 2013). Over time, agricultural practices shifted toward extensification, characterized by the expansion of cultivated areas. It has been argued that this transition to extensive farming, with its emphasis on larger areas of land use, increased the importance of land ownership and spurred wealth accumulation, laying the groundwork for further social diversification and increased complexity (Mulder et al. 2009; A. Styring, Charles, and Fantone 2017). Agricultural strategies in Mesopotamia varied not only chronologically, but also geographically. In the arid south, farmers employed intensification techniques, such as irrigation and soil fertilization, to boost yields and expand arable land (Algaze 2008; Styring, Charles, and Fantone 2017). In contrast, the rainfed northern regions favored extensification, expanding cultivated land while minimizing labor costs. These approaches were tailored to the biological traits of domesticated plants, seasonal cycles, and soil conditions specific to dry-farming zones (Stroud, Bogaard, and Charles 2021; Styring, Charles, and Fantone 2017; Maltas et al. 2022; Bogaard and Hodgson 2018).

3. Methods

The presented PhD dissertation research is based on the comprehensive study of a exclusively new archaeobotanical data from three sites: Tel Qedesh in Northern Israel, Kani Shaie in Iraqi Kurdistan, and Gurga Chiya, also in Iraqi Kurdistan. Additionally, author collected and used modern olives, picked from a single tree located in Mount Herzl in Western Jerusalem, Israel, and purchased modern grape samples from certified organic farm from Murcia region, Southwestern Spain. Moreover, the material from Tepe Marani, a Neolithic settlement adjacent to Gurga Chiya, was used for isotope studies. During the implementation of the project, the author was responsible for collecting and analyzing the archaeobotanical samples used for this project herself, which meant participating in the excavation missions, as well as establishing the sampling, flotation and sorting methodology. Therefore, the author spent around three months in the years 2021-2024 participating in the fieldwork. Throughout the implementation of the project, the author developed complex skills in the various facets of analysis of archaeobotanical materials, including stable isotope analysis, during numerous laboratory visits and internships.

The chronological scope of the project comprises the period in which the targeted processes in Southwest Asia took place. Therefore, the selected three sites represent their subsequent phases. Neolithic patterns in archaeobotany are already heavily studied, but less data is available from subsequent periods of the Chalcolithic up to the Bronze Age, and this is notably the case of Iraqi Kurdistan, where the systematic sampling has only begun recently. Thus Gurga Chiya, Kani Shaie and Tel Qedesh comprised new important primary datasets, which allowed the recognition of the process of crop cultivation and commodification, and contributed to the expansion of existing datasets, which can be used for further analysis by the entire research community.[1]

The standard and optimal archaeobotanical sampling method was applied in this project (Wasylikowa and Lityńska-Zając 2005). The basic tool kit of archaeobotany is systematic collection of plant remains (by flotation), sorting under low magnification and identification alongside a reference collection and regional atlases. After extracting the samples, the first aspect of the research is a statistical analysis of assemblage composition (ubiquity, relative frequency, and selected intertaxon ratios). Crop processing was assessed through established methods of ratios of grains, chaff and weed seed groups. Selected crops were measured and photographed to document potential morphological and morphometric changes. Finally, selected grains have been singled out for SIA ($\delta^{13}C$, $\delta^{15}N$) as these methods are helpful in identifying manuring and irrigation.

[1] The tables presenting the overviews of the archaeobotanical assemblages from 3 sites of Gurga Chiya, Kani Shaie and Tel Qedesh are added in *Supplementary data* of the presented dissertation

Plant stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope ratios vary in relation to a range of environmental factors (Bogaard et.al. 2013). Plant $\delta^{13}C$ values have been primarily applied to investigate crop water management practices, since it is proven that plant water status has an impact on carbon isotope composition ($\delta^{13}C$) (Fiorentino et al. 2014). It is also proved, that soil with high concentration of organic nitrogen – affected by manuring, animal tillage, or just naturally rich soil – have higher $\delta^{15}N$ element, than unfertilized ground which is also mirrored in archaeobotanical remains (Fiorentino et al. 2014). Both methods are experimentally proved on the range of archaeological sites to determine the environmental conditions of plants' growth. As such research has been performed commonly for cereals, but hardly for perennial plants, the considerable part of presented work focused on the applicability of stable isotope analytical methods previously developed for cereals and pulses, for the study of perennial plants. The processes of commodification of plants, or anything else, cannot be determined from artifacts or bioarcheological data alone. Therefore, it was crucial to contextualize archaeobotanical analysis with archaeological – artifactual, architectural and chronological – data. The management of food resources and commodification processes was recognized within the architectural and artifactual context of its storing: this is due to the size and location of the storage space (public or private premises), the type of access (free/restricted), and the accompanying items – vessels, stamp seals, sealings (Joka 2025).

4. Materials

To gain a comprehensive understanding of the phytosphere at the site—encompassing the morphological characteristics of selected plants and the diachronic changes in crop repertoire—it is recommended to examine the site's entire archaeobotanical assemblage. Therefore, before selecting the contexts critical to this dissertation, the entirety of the samples collected from three abovementioned sites was archaeobotanically analyzed. It included 179 samples from Tel Qedesh, 56 samples from Gurga Chiya, and 235 samples from Kani Shaie. The analyzed material was then carefully selected to exclude samples that would falsify the results of the work, due to chronological or contextual irrelevance. The final step was to select the samples for further SIA. Below is a full description of the samples used in the doctoral thesis.

Tel Qedesh

The study of the Tel Qedesh samples was aimed to assess the applicability of Stable Isotope Analysis (SIA) for perennial plants from archaeological contexts. The selection of archaeological material was based on undisturbed layers containing grape and olive seeds.

Consequently, 26 well-preserved, undamaged, and fully charred remains of grapes (*Vitis vinifera*, 10 specimens) and olives (*Olea europaea*, 16 specimens) from 13 contexts across two areas—an Early Bronze Age (EB) I-II fortification (four secondary contexts) and an EB II residential area (nine primary contexts)—were chosen for isotopic analysis. Additionally, six modern fruit samples (three grapes and three olives) were included for comparative purposes.

Kani Shaie

The archaeobotanical assemblage collected from Kani Shaie provides the opportunity to contextualize the issues of determining the commodification processes of plants. 14 samples rich in archaeobotanical material (1.204 seeds and seed fragments, mostly legumes and cereals, with very few arable weeds) have been collected from the contexts interpreted as part of a foodstuff distribution area adjacent to the grilled structure, which also featured administrative instruments such as seals, used both to seal the containers for seeds and the doors. These were then studied archaeobotanically according to the protocol presented above. The architectural layout and associated artefacts indicate that these spaces were not used for domestic purposes but were instead restricted areas dedicated to the storage and distribution of food.

Gurga Chiya

The study of the Gurga Chiya materials was aimed to contribute to the 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. Hence, the selected contexts were related to the food storage activity at the site.

From the total of 21primarily analyzed samples, 12 samples from storage and storage-related contexts from Late Ubaid Gurga Chiya's assemblage were included into this research. This assemblage contained an extremely high proportion of archaeobotanical remains with a total number of 30,300 seeds (mostly lentils and barley), seed fragments and food remain. Archaeological data suggests that the storage belonged to an individual domestic unit, and combined with the archaeobotanical data, implies the high economic independence of the household.

The archaeobotanical material (4 seeds of emmer wheat, 7 barley seeds and 8 lentils) from 11 contexts was then selected for further analysis of $\delta^{13}C$ and $\delta^{15}N$ isotopic values, in addition to 3 contexts selected from Late Neolithic levels of Tepe Marani.

5. Results

The processes of plants commodification took place during the transition period between Late Neolithic and Early Bronze Age, that is– between small-scale crops, whose purpose was to meet the needs of the local community, and cash crops, resulting from the stabilization of society and food surpluses. The study of materials from Late Ubaid settlement at Gurga Chiya and Early Bronze Age settlement at Kani Shaie made it possible to infer the diachronic trajectory of commodification processes and to place them in social and economic contexts, both in relation to the settlement inhabitants and regionally.

At the Late Ubaid site of Gurga Chiya, evidence suggests the storage of agricultural crops in quantities exceeding the basic needs of a single household. This surplus likely enabled reciprocal exchanges and activities within the community. Notably, the significant quantities of lentils, compared to cereals, may reflect seasonal crop availability or differing culinary uses, such as wheat being processed into porridge or bread (Carter and Wengrow 2020). The storage areas appear to belong to individual domestic units, suggesting an increasing degree of economic autonomy for large households (Carter and Wengrow 2020).

The absence of processing waste, such as pods and chaff, in associated deposits indicates that crops were processed prior to storage, possibly outside the buildings. This pattern is consistent with other 'Ubaid sites, including Tell Abada and Kenan Tepe (Jasim 2021; Graham 2011; Graham and Smith 2015). Such activities would have required significant communal effort, implying reciprocal arrangements among village units or the involvement of large, multigenerational families engaged in seasonal cooperative harvesting (Fuller and Stevens 2009).

A further indication of growing household autonomy during the 'Ubaid period is the general lack of evidence for administrative control over surpluses. This contrasts with both earlier Late Neolithic and later Chalcolithic/Early Bronze Age contexts, where surplus management was often tied to centralized administration (M. Frangipane 2007; Akkerman and Duistermaat 2004). Stable isotope analysis (SIA) from Gurga Chiya, compared with the earlier Late Neolithic site of Tepe Marani, reveals significant changes in cereal cultivation practices. These findings suggest a gradual shift towards more extensive cultivation systems with lower inputs per unit area over time (cf. Diffey et al. 2020; Styring, Charles, and Fantone 2017).

This developmental trajectory aligns with broader models contrasting late Neolithic intensive agriculture with early historical extensification (Styring, Charles, and Fantone 2017; Maltas et al. 2022; Diffey et al. 2020). However, drawing firm conclusions about the ‘Ubaid period’s role in these transitions requires additional data from contemporaneous sites to address gaps in the environmental record from the 5th millennium BCE.

The archaeobotanical and archaeological evidence of specialized storage at Gurga Chiya provides an opportunity to explore early commodification processes while reevaluating assumptions about the Late ‘Ubaid period. For instance, it is often argued that specialized storage and economic surpluses are closely linked to social stratification and the rise of elites who capitalize on these surpluses to consolidate political power (Frangipane 2007; Algaze 2008; Stein 2020). The ‘Ubaid period is frequently viewed as a transitional stage between egalitarian Neolithic villages and the emergence of state-level societies and hierarchies characterized by chiefdoms (e.g., Stein 1994; Algaze 2008; with early critiques by Yoffee 1993).

However, evidence from earlier Late Neolithic (Halaf) sites in northern Mesopotamia, such as Tell Sabi Abyad (Akkermans and Duistermaat 1996) and Yarim Tepe II (Merpert and Munchaev 1993)), challenges the notion that food surpluses inherently lead to social inequality (Wengrow 1998). At Gurga Chiya, the emergence of specialized storage within individual households replaces earlier patterns of communal storage, indicating a shift in surplus management.

While extended households may have gained greater economic autonomy during the Late ‘Ubaid period, this does not necessarily imply formal social hierarchies. Instead, such developments may reflect new interdependencies among households, including coordinated exchanges of crop surpluses. These dynamics may have enabled agricultural specialization at a local scale, shaped by the affordances of specific crops and micro-environments, as evidenced by the archaeobotanical data from Gurga Chiya.

Archaeological and botanical data from Kani Shaie provided valuable information on the commercialization of crops from the much later Early Bronze Age, allows to infer on the role of small- scale administrative centers in the commodification of plant resources, both preceding and existing outside major centers of urbanization. The archaeological and botanical evidence from Kani Shaie provides valuable insights into early crop commodification processes. In reference to the abovementioned Kopytoff’s (1986) definition, commodification involves transforming goods into items of distinct value, either physically or symbolically, setting them apart from everyday items. At Kani Shaie, features such as a restricted-access granary, sealed storage units, and the precise portioning of crops indicate early forms of commodification.

These practices added value to stored crops, not only as tangible commodities but also within a system of redistribution.

While these characteristics suggest commodification, there is no direct evidence of trade or market-based exchanges comparable to those in the urbanized centers of Mesopotamia. Instead, Kani Shaie appears to have operated under a centralized redistribution model. Agricultural surpluses were collected, stored, and distributed either within the community or possibly to external groups. Kani Shaie's strategic location, between the Zagros Mountains and the Mesopotamian lowlands, highlights its potential significance as a regional exchange hub. Evidence dating back to the 5th millennium BCE suggests that the site functioned as a central node in the Bazyan Valley, potentially serving as a stopover for travelers or nomadic pastoralists moving between the highlands and lowlands (Tomé, Cabral, and Renette 2016). This advantageous position likely supported its role in facilitating mobile groups and managing surplus crops for wider distribution. The increasing scale of agricultural production at Kani Shaie lends support to the idea that centralized distribution systems emerged in response to surplus accumulation. The presence of seals, sealings, and restricted-access storage further indicates measures to monitor and manage the movement of goods, reinforcing its role in an organized redistribution system. This system likely supported not only the local community but also mobile or specialized groups, such as craftsmen and traders, emphasizing the multifaceted roles rural settlements played within broader economic networks (Schwartz 2015; M. Frangipane 2007). The example of Kani Shaie illustrates that processes such as centralization and commodification were not limited to urban centers. Evidence of surplus management, redistribution, and administrative practices at this small rural settlement challenges traditional perspectives that associate these features solely with urbanization (Graeber and Wengrow 2021). The site underscores the diverse pathways leading to social complexity in Early Bronze Age Mesopotamia. Findings from Kani Shaie contribute to a growing body of research showing how agricultural production and resource management laid critical foundations for social complexity. By examining these processes across a variety of sites and settlement sizes, we can gain a more nuanced understanding of the origins of urbanization and the emergence of elements commonly linked to complex societies.

The results from Gurga Chiya and Kani Shaie imply that plant commodification was a gradual process and, in both cases, reflected a broader economic system. The summary of research from both settlements presents a complex process of plant commodification mechanisms. Diachronically, we can see the transition from small-scale communal food distribution, confirmed by Neolithic sources, through private stocks belonging to extended households, to storage complexes probably managed centrally and redistributing supplies throughout the larger community. Both the beginnings of commodification processes and the determination of the exact point at which plants were commodified are disputable, but gradual changes towards commodification are discernible, and can be determined archaeologically and via archaeobotanical remains.

Important, but largely overlooked factor in the trajectories of social complexity is the cultivation and commodification of perennial plants. The emergence of perennial fruit cultivation represents a significant shift in past land use, involving long-term investments in land as well as the transformation and commodification of specific crops. It has been suggested that this development was closely linked to urbanization and growing social complexity in the parts of Eurasia, as some researchers indicate the possibility that fruit crop commodification and specialization in animal secondary products emerged in parallel in many Eurasian societies (Mccoriston 1997; Sherratt 1999; Fuller and Stevens 2009) and are part of *investment agriculture* phenomenon. In this context, the role of perennial plants in shaping the administrative organization of early states and urbanism is arguably comparable to that of craft industries such as textile production, masonry, and metallurgy. However, the processes involved in managing and transforming perennial fruit crops—from small home gardens to the large-scale orchards known from the Bronze Age—remain underresearched. In Southwest Asia, the earliest instances of arboreal domestication, which were both preceded and accompanied by cultivation, likely occurred between 6,500 BCE and 3,500 BCE, as evidenced by morphological and morphometric analyses of archaeobotanical macroremains (Fuller & Stevens, 2019). During this period, the production of both annual and perennial agricultural crops steadily increased, with many crops being transformed into widely traded commodities. While the extensification of cereal agriculture has been linked to the rise of the earliest cities in western Asia (Styring, Charles, and Fantone 2017), the role of arboriculture in this process remains under-researched. This is despite its importance in understanding crop product exchange, production organization, and their connections to early urban development in the region (Fuller & Stevens, 2019). As a result, much of our knowledge of arboricultural techniques comes from historical periods, when these crops had already become integral to the agricultural economy (Childe 1950; Naomi Miller and Wetterstrom 2000; Weiss 2015; Dorian Fuller and Stevens 2019). One methodological approach for delving deeper in time in the search for insights into perennial management, that has shown immense promise for studying the past management of domesticated cereals and legumes, is stable carbon and nitrogen isotope analysis of charred plant remains. In order to investigate the potential of stable isotope analyses to explore the management of perennial plants in the past, I applied stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope determinations to the ancient olives (*Olea europea* L.) and grapes (*Vitis vinifera* L.*)* from Tel Qedesh archaeological site, located in the Upper Galilea, Israel .I evaluated (i) the applicability of stable isotope analytical methods previously developed for annually grown plants for the study of perennial plants and identified (ii) i potential opportunities and limitations of the above-mentioned methods in the study of perennial crop cultivation practices among past societies in the Levant.

Performed experiment shown that the methods of analyzing $\delta^{13}C$ plant stable isotope previously applied for the study of annual crops are transferable to perennial plants material from archaeological contexts. The $\Delta^{13}C$ values for grapes are generally higher than those of other plants, such as cereals (wheat, barley) and legumes (lentil, broad bean), as well as olives (Wallace et al. 2013; Ehrlich et al. 2022; Brillante et al. 2020). Modern studies show that grapes have high drought tolerance, with fruit typically forming during dry summer months in regions with scarce precipitation (Brillante et al., 2020). Drought-resistant plants like barley tend to show higher $\Delta^{13}C$ values when watered compared to drought-sensitive ones like wheat (Wallace et al., 2013). Therefore, it is expected that grapes would have higher $\Delta^{13}C$ values than more water-sensitive plants in the same habitat. Grapes may also be highly sensitive to water input, similar to legumes, which show isotopic shifts depending on their environment (Wallace et al., 2013). As for olives, comparable research performed on the olives from archaeological and paleontological sites by Ehrlich et al. (2022) determines the $\Delta^{13}C$ value of arid and optimal conditions. Based on their findings, the EBA II period, from which the discussed olive remains come, was identified as more arid, reflected in lower $\Delta^{13}C$ values from various archaeological sites. The $\Delta^{13}C$ values of olives from Tel Qedesh suggests favorable growing conditions, and these values align with those from other sites of the same period, with similar annual precipitation (500–600 mm) (Ehrlich et al., 2022).

Unfortunately, none of the olive or grape samples contained a nitrogen content abundant enough to obtain a readable nitrogen value. This observation is explained by the nitrogen metabolism of fruits, as nitrogen comes from the protein components of plants, which are not very abundant in fruit stones/pipes. Successful trials have been conducted to obtain $\delta^{15}N$ values from modern olives and grapes to assess the impact of organic vs. synthetic fertilizers on nitrogen isotope composition (olive leaves and drupes) (Benincasa, Pellegrino, and Perri 2018) and to evaluate how terroir affects $\delta^{13}C$ and $\delta^{15}N$ values in grapes (Santesteban et al. 2012). These studies encourage further research on the application of stable isotope analysis to determine the growing conditions of perennial plants, incorporating various annual plant parts. Although nitrogen was preserved in the seed samples tested, the EA-IRMS system used in this study lacked the sensitivity needed to obtain reliable $\delta^{15}N$ values, highlighting the need for future methodological improvements with higher sensitivity. A further route of analysis in this regard might be analysis of dried olive and grapevine fruit remains, as has been found in some contexts in Southwest Asia and North Africa.

Finally, the absence of previous research on $\delta^{15}N$ values for olive, grapevine, or other perennial fruit plants from archaeological contexts in Southwest Asia makes current datasets challenging to interpret. This gap highlights the need for further expansion and investigation beyond analytical issues. As a result of my research, I propose a multi-stage plan to address these challenges as follows:

i. Isotopically analyze modern, uncharred fruits and fruit parts (seeds, flesh, rind) from plots with well-documented and differentiated growing conditions, including climate, weather, and manuring/watering regimes.
ii. Perform EA-IRMS analysis on multiple, sensitive instruments, ideally suited for low-nitrogen-containing samples.
iii. Conduct charring experiments on selected modern remains to identify potential charring offsets.
iv. Isotopically examine species from archaeological contexts (e.g., dried fruit remains) using comparable plant parts (seeds, whole fruit, skin).
v. Study isotopic values of olive and grape remains from archaeological contexts, where relevant paleoenvironmental or historical data on crop management are available for comparison.

The experiments conducted on selected perennials in this study have allowed us to identify crucial problems with application of the $\delta^{13}C$ and $\delta^{15}N$ analysis to archaeological olives and grapes. We present a proposed research plan to address some of the major challenges identified in applying this methodology in future studies. The integration of archaeological, archaeobotanical, and isotopic methods will enable future discussions on the cultivation and commodification processes of perennial plants. This, combined with data on annual cultivars, will provide a comprehensive understanding of plant commodification and its cultural impact within the pathways of social complexity.

6. An impact of PhD research

The presented PhD dissertation makes a significant contribution to the hitherto limited knowledge on plant cultivation and commodification in late prehistory, while at the same time defining new theoretical frameworks for this issue. It advocates that the commodification mechanisms be anchored in empirical research – both archaeological and archaeobotanical – within the archaeological sites of Southwest Asia. This work offers first critical insights into the previously overlooked mechanisms of crops commodification, how they are reflected and entangled in socio-economic realities, as well as the culture forming impact of plants' commodification.

Another crucial achievement of this dissertation is the development and implementation of innovative methods. One of its objectives was to recognize an impact of the developed agricultural practices as well as food production as the drivers of its increasing social complexity. Therefore, modern tools for recognizing past plant cultivation were used, including stable isotope analyses, which were conducted both in a previously established form (on cereals and legumes) and in an experimental form (on perennial plants). My research makes the first step toward a better understanding of perennial plant cultivation methods and has also significantly contributed to the advancement of stable isotope analysis techniques in archaeobotanical research.

The methodological and theoretical aspects developed in this work are universal in nature and can be adapted for archaeological research regardless of the era or region. Meanwhile, the results derived from the analyzed case studies contribute to more comprehensive understanding of plant cultivation and commodification in Southwest Asia. However, the research carried out as a part of the PhD dissertation does not fully exhaust the topic of plant commodification and its cultural significance. This highly complex process shall require further research efforts, at both theoretical and practical level, and my research is an important contribution to these ongoing works.

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Znaczenie kulturowe upraw i komodyfikacji roślin w okresach chalkolitu oraz wczesnej epoki brązu w Azji Południowo-Zachodniej na przykładzie stanowisk Gurga Chiya z późnej fazy kultury Ubaid (Iracki Kurdystan), Kani Shaie z okresu wczesnej epoki brązu (Iracki Kurdystan) oraz Tel Qedesh z okresu wczesnej epoki brązu (Izrael).

Główne tezy rozprawy doktorskiej

1. Wstęp

Udomowienie roślin i późniejsze pojawienie się rolnictwa to jedne z kluczowych czynników rewolucji neolitycznej, które zapoczątkowały szereg zmian gospodarczych i społecznych (np. Miller 2000, Boivin 2016). Rolnictwo wpłynęło na krajobraz (pola uprawne, wylesianie), społeczeństwo (osiadły tryb życia, magazynowanie plonów) oraz ekologię (udomowienie roślin i zwierząt) (Fuller 2016). Jednym ze skutków uprawy ziemi był wzrost populacji, który wiązał się z pojawieniem się specjalizacji pozarolniczych oraz rozwinięciem bardziej rozległych form dystrybucji dóbr i handlu (Scott 2017). W Azji Południowo-Zachodniej różnica czasowa między pojawieniem się rolnictwa, organizacją pól uprawnych a powstaniem pierwszych miast wynosi około 5000 lat (Boivin, Zeder i in. 2016). Powszechnie przyjmuje się (Sherratt 1999; Fuller i Stevens 2019; Fuller i Stevens 2009; Frangipane 2018), że w tym okresie uprawiano i udomawiano rośliny wieloletnie (takie jak oliwka, winorośl, figa, granat i daktyl) (Fuks i in. 2020; Langgut 2024; Joka i in. 2024), które stanowiły fundament dla późniejszego rozwoju tzw. „upraw towarowych” (ang. *cash crops*). Jednocześnie uprawa zbóż przeszła liczne transformacje mające na celu uzyskanie bardziej efektywnych plonów (Bogaard i in. 2013; 2017; Stroud, Bogaard i Charles 2021; Styring i in. 2022). Obie te kategorie, a także produkty wtórne roślin (np. wino, olej, suszone owoce), uległy procesom komodyfikacji, stając się towarami na rynku sprzedaży.

Podczas gdy pierwsze etapy tego procesu zostały szeroko zbadane, późniejsza faza pozostaje w dużej mierze niedostatecznie rozpoznana. Moje badania doktorskie dotyczą trzeciego etapu powyższego procesu i mają trzy wzajemnie powiązane cele:

1. Rozpoznanie procesu i mechanizmów komodyfikacji roślin oraz ich kulturotwórczego wpływu, zwłaszcza w kontekście wzrostu złożoności społecznej w północnej Mezopotamii.
2. Zbadanie procesu i mechanizmów pojawienia się nowych praktyk rolniczych, w tym metod intensyfikacji i ekstensyfikacji, wprowadzenia nowych upraw – zwłaszcza roślin wieloletnich – oraz trwałego wpływu zaawansowanych procesów rolniczych, takich jak

celowe opóźnienie zwrotów z inwestycji, na rosnącą złożoność społeczną w Azji Południowo-Zachodniej.

3. Analiza zastosowania wyników badań izotopów stabilnych na materiale archeobotanicznym jako narzędzia wspierającego rozpoznanie procesów komodyfikacji

Badania zrealizowane w ramach przedłożonej pracy doktorskiej obejmują okres od V do początku III tysiąclecia p.n.e., czyli czas rozwoju zaawansowanego rolnictwa i powiązanych praktyk w Azji Południowo-Zachodniej. Z kulturowo-historycznego punktu widzenia obejmuje to okres od późnego neolitu do wczesnej epoki brązu. Cele badawcze zostaną osiągnięte poprzez kompleksową analizę materiałów botanicznych i archeologicznych z trzech stanowisk w badanym regionie:

1. **Gurga Chiya, iracki Kurdystan** – późny chalkolit
2. **Kani Shaie, iracki Kurdystan** – wczesna epoka brązu
3. **Tel Qedesh, Izrael** – wczesna epoka brązu

Wyniki badań zostały opublikowane w trzech artykułach recenzowanych, znajdujących się na liście A Ministerstwa Nauki i Szkolnictwa Wyższego. Każda z publikacji porusza odmienny aspekt szeroko rozumianego procesu komodyfikacji upraw rolnych.

Artykuł *Exploring the potential of stable carbon and nitrogen isotope analysis of perennial plants from archaeological sites: A case study of olive pits and grape pips from Early Bronze Age Qedesh in the Galilee* (Joka et al. 2024) koncentruje się na zastosowaniu analizy stabilnych izotopów węgla (δ13C) i azotu (δ15N) do badania szczątków oliwek i winogron w celu określenia metod ich uprawy w przeszłości. Oliwki i winogrona należały do pierwszych i najczęściej uprawianych roślin owocowych (od wczesnego chalkolitu) oraz do głównych towarów handlowych (od wczesnej epoki brązu). Mimo to metody ich uprawy przed pojawieniem się źródeł pisanych pozostają słabo poznane. Artykuł ten wypełnia lukę badawczą, po raz pierwszy stosując analizę izotopów stabilnych do badania roślin wieloletnich w kontekście archeologicznym. Publikacja podsumowuje dotychczasowe badania dotyczące uprawy roślin wieloletnich, wskazuje potencjalne problemy metodologiczne związane z analizą izotopową oraz proponuje opracowanie nowego modelu interpretacyjnego. Na podstawie wyników eksperymentów opracowano kompleksowy plan rozwoju metodologii, bazując na wcześniejszych modelach stosowanych do badań zbóż i roślin strączkowych. Finalnie, przeprowadzone badania eksperymentalne wykazały, że oliwki z wczesnej epoki brązu (II) z

Tel Qedesh w Górnej Galilei charakteryzowały się wysokim stopniem nawodnienia w czasie wzrostu, co rzuca nowe światło na warunki ich uprawy.

Artykuł *Plant Commodification in Northern Mesopotamia: Evidence from the Early Bronze Age Site of Kani Shaie, Iraqi Kurdistan* (Joka 2025) przedstawia nowe dowody na wczesną dystrybucję i komodyfikację nadwyżek rolnych w niewielkiej społeczności z wczesnej epoki brązu (EBA) w Kani Shaie, położonej w Dolinie Bazyan w irackim Kurdystanie. Analiza archeobotaniczna (szczątki zbóż i roślin strączkowych) oraz archeologiczna (pieczęcie) wskazują, że kompleks architektoniczny z tego okresu pełnił funkcję magazynu żywności oraz centrum jej redystrybucji. Strategiczne położenie Kani Shaie na skrzyżowaniu Gór Zagros i nizin Mezopotamii podkreśla jego kluczową rolę w sieciach mobilności, łączących obszary górskie i nizinne. Badania te rzucają nowe światło na znaczenie małych, peryferyjnych ośrodków administracyjnych w procesie komodyfikacji zasobów roślinnych, zarówno przed, jak i po powstaniu większych ośrodków miejskich. Wskazują one, że nawet niewielkie społeczności uczestniczyły w organizacji nadwyżek żywności i ich dystrybucji, co mogło mieć istotne konsekwencje dla rozwoju gospodarki i struktur społecznych w regionie.

Artykuł *Storage story: investigating food surplus and agricultural methods in Late Ubaid Gurga Chiya (Iraqi Kurdistan)* (Joka et al. 2025) bada praktyki rolnicze oraz rozwój społeczny w północnej Mezopotamii w okresie późnego Ubaidu (V tysiąclecie p.n.e.), koncentrując się na stanowisku Gurga Chiya w irackim Kurdystanie.Publikacja łączy analizę archeologiczną, architektoniczną i archeobotaniczną, aby zbadać związek między magazynowaniem roślinnych zapasów żywności a gospodarką domową w Gurga Chiya. Celem jest lepsze zrozumienie, w jaki sposób praktyki przechowywania żywności przyczyniły się do szerszych przemian społeczno-ekonomicznych w regionie. Dowody z Gurga Chiya wskazują na magazynowanie nadwyżek rolnych, zwłaszcza soczewicy, w ilościach przekraczających potrzeby pojedynczych gospodarstw domowych. Sugeruje to istnienie wymiany wzajemnej lub ekonomiczną autonomię dużych, wielopokoleniowych gospodarstw. Przeniesienie przechowywania zbiorów z przestrzeni wspólnotowych do indywidualnych gospodarstw domowych świadczy o rosnącej niezależności gospodarstw, choć niekoniecznie o istnieniu formalnych hierarchii społecznych. Analiza przestrzenna i archeobotaniczna została uzupełniona badaniem stabilnych izotopów wartości $\Delta^{13}C$ i $\delta^{15}N$ zachowanych ziaren z Gurga Chiya oraz sąsiedniego, późnoneolitycznego stanowiska Tepe Marani. Pozwoliło to na diachroniczne spojrzenie na zmiany w metodach uprawy roślin. Wyniki sugerują, że w miarę upływu czasu praktyki rolnicze ewoluowały od intensywnej uprawy do bardziej ekstensywnych metod, co mogło mieć dalekosiężne skutki dla organizacji społeczno-ekonomicznej w regionie.

2. Ramy koncepcyjne i teoretyczne

Kluczowym tematem tej rozprawy doktorskiej jest zjawisko utowarowienia roślin (zbóż i roślin wieloletnich): jego początki, rozwój oraz długotrwałe znaczenie w kontekście przeszłych gospodarek i rozwoju rolnictwa przed powstaniem pierwszych miast.

Utowarowienie jest w tej pracy rozumiane jako proces nadawania wartości zasobom – takim jak plony rolne, przetwarzane na potrzeby przechowywania lub wymiany, surowce przekształcane w artefakty, zasoby naturalne (np. woda, kamień, drewno) lub nieruchomości (np. linie brzegowe, ziemia uprawna, budynki). Proces ten osiąga swoje apogeum, gdy zasób zostaje oznaczony jako towar i wymieniany na równoważnik wartości. Jednak to, czy zasób staje się towarem, zależy od jego kontekstu społecznego, który może się różnić w zależności od grup i jednostek (Kopytoff 1986).

W okresie od późnej epoki neolitu do wczesnej epoki brązu na obszarze Azji Południowo-Zachodniej, zarówno rośliny jednoroczne (zboża i rośliny strączkowe), jak i wieloletnie, przeszły procesy utowarowienia i stały się produktami o wartości wymiennej. Rośliny uprawiane na potrzeby wyżywienia społeczności, takie jak zboża i rośliny strączkowe, zyskiwały wartość poprzez magazynowanie w dużych ilościach, podczas gdy rośliny wieloletnie, takie jak oliwki, winorośle czy figi, zwiększały swoją wartość poprzez przetwarzanie na produkty wtórne, takie jak oliwa z oliwek, wino, bądź suszone owoce (rodzynki, figi, wysokokaloryczne i łatwe w transporcie).

Istotnym aspektem w procesie utowarowienia roślin w Azji Południowo-Zachodniej była uprawa i późniejsze utowarowienie roślin wieloletnich, co stanowiło kluczowy element procesu społecznej i ekonomicznej dywersyfikacji w epoce brązu. Ostatecznie doprowadziło to do powstania rolnictwa inwestycyjnego i upraw towarowych (*cash crops*), które uważa się za jeden z filarów wczesnych gospodarek miejskich. Fenomen rolnictwa inwestycyjnego odnosi się do formy gospodarowania ziemią wymagającej długoterminowego nakładu pracy przy akceptacji przedłużonego okresu wzrostu roślin przed zbiorem i osiągnięciem zysków. Przyjmuje się, że odegrało ono kluczową rolę w kształtowaniu praw własności ziemi i społecznej stratyfikacji (Renfrew 1972; Sherratt 1999). Rośliny uprawiane w ramach upraw towarowych to gatunki, które nie przyczyniają się bezpośrednio do przetrwania, ale są produkowane na potrzeby rzemiosła lub handlu (Sherratt 1999).

Proces utowarowienia jest nieodłącznie związany z nadwyżkami żywności, czyli zjawiskiem ekonomicznym, które pojawiło się wraz z rozwojem społeczności rolniczych i doprowadziło do powstania grup zawodowych niezwiązanych z rolnictwem, a z rzemiosłem bąfć handlem. Sam temat nadwyżek żywności jest jednym z najczęściej dyskutowanych tematów w antropologii i archeologii wczesnych społeczeństw (Bogaard 2017; Hastorf i Foxhall 2017; Saitta 2016; Sherratt 1999).

Jak podkreślają Hastorf i Foxhall w pracy *The Social and Political Aspects of Food Surplus* (2017), nadwyżka wykracza poza sferę ekonomiczną, obejmując także aspekty biologiczne, społeczne i psychologiczne. Nadwyżka żywności może być związana z poczuciem zbiorowego bezpieczeństwa, zapewniając przetrwanie i umożliwiając uczestnictwo w praktykach kulturowych i społecznych, takich jak darowizny, uczty i wymiana wzajemna (Hastorf i Foxhall 2017). Alternatywnie, produkcja nadwyżek mogła być napędzana przede wszystkim względami społecznymi i kulturowymi – np. ceremoniami czy ucztami rytualnymi – a nie tylko potrzebami przetrwania.

Archeolodzy rozważali także gromadzenie nadwyżek plonów i utowarowienie w odniesieniu do nowych strategii produkcji żywności, w tym zarówno intensyfikacji, jak i ekstensyfikacji praktyk rolniczych (Sherratt 1999; Fuller i Stevens 2009). Intensyfikacja polegała na zwiększeniu i podtrzymywaniu nakładu pracy na jednostkę ziemi poprzez metody takie jak orka, skracanie okresów ugoru, wzbogacanie gleby przez nawożenie, nawadnianie oraz strategiczny wysiew roślin w siedliskach najlepiej odpowiadających ich wymaganiom biologicznym (Sherratt 1981; Fuller i Stevens 2009; Styring, Charles i Fantone 2017; Bogaard i in. 2013). Ekstensyfikacja natomiast koncentrowała się na rozszerzaniu użytkowania gruntów rolnych poprzez stosowanie technik oszczędzających pracę, takich jak orka pługiem, oraz zwiększanie powierzchni upraw.

Badania sugerują, że w okresie neolitu uprawa ziemi opierała się głównie na pracochłonnych technikach takich jak nawożenie i orka, zwykle prowadzonych na mniejszych poletkach (Styring i in. 2017; Bogaard i in. 2013). Z biegiem czasu praktyki rolnicze przesunęły się w kierunku ekstensyfikacji, charakteryzującej się rozszerzaniem obszarów uprawnych. Uważa się, że ta zmiana w stronę bardziej ekstensywnego rolnictwa zwiększyła znaczenie własności ziemi i przyczyniła się do akumulacji bogactwa, co utorowało drogę do dalszej dywersyfikacji społecznej i wzrostu złożoności społecznej (Mulder i in. 2009; Styring, Charles i Fantone 2017).

Strategie rolnicze w Mezopotamii różniły się nie tylko w czasie, ale także geograficznie. Na suchych terenach południowych rolnicy stosowali techniki intensyfikacyjne, takie jak nawadnianie i nawożenie gleby, aby zwiększyć plony i powiększyć areał ziemi uprawnej (Algaze 2008; Styring i in. 2017). W północnych regionach, gdzie rolnictwo było zależne od opadów deszczu, preferowano ekstensyfikację, polegającą na zwiększaniu obszaru upraw przy jednoczesnym minimalizowaniu kosztów pracy. Te podejścia były dostosowane do cech biologicznych udomowionych roślin, cykli sezonowych oraz warunków glebowych charakterystycznych dla stref rolnictwa suchego (Stroud, Bogaard i Charles 2021; Styring, Charles i Fantone 2017; Maltas i in. 2022; Bogaard i Hodgson 2018).

3. Zakres badań i metodologia

Przedstawiona rozprawa doktorska opiera się na kompleksowym badaniu wyłącznie nowych danych archeobotanicznych pochodzących z trzech stanowisk: Tel Qedesh w północnym Izraelu, Kani Shaie w irackim Kurdystanie oraz Gurga Chiya, również w irackim Kurdystanie. Ponadto autorka zebrała i wykorzystała współczesne próbki oliwek, które pochodziły z pojedynczego drzewa na Górze Herzla w zachodniej Jerozolimie, oraz zakupiła próbki winogron z certyfikowanej ekologicznej farmy w regionie Murcji w południowo-zachodniej Hiszpanii. Dodatkowo do badań izotopowych wykorzystano materiał z Tepe Marani – neolitycznego osiedla sąsiadującego z Gurga Chiya.

W ramach realizacji projektu autorka była odpowiedzialna za pobieranie i analizę próbek archeobotanicznych, co wiązało się z udziałem w pracach wykopaliskowych oraz opracowaniem metodologii pobierania próbek, flotacji i sortowania. W związku z tym autorka spędziła łącznie około trzech miesięcy w latach 2021–2024 na badaniach terenowych. W trakcie realizacji projektu rozwinęła swoje umiejętności w zakresie analizy materiału archeobotanicznego podczas licznych wizyt laboratoryjnych i staży.

Chronologiczny zakres projektu obejmuje okres, w którym na terenie Azji Południowo-Zachodniej miały miejsce ww. wymienione procesy. Dlatego wybrane trzy stanowiska reprezentują kolejne fazy tych przemian. Neolityczne wzorce w archeobotanice są już dobrze udokumentowane, jednak istnieje znacznie mniej danych dotyczących kolejnych okresów – od chalkolitu po epokę brązu – co jest szczególnie widoczne w przypadku irackiego Kurdystanu, gdzie systematyczne pobieranie próbek rozpoczęło się dopiero niedawno. W związku z tym Gurga Chiya, Kani Shaie i Tel Qedesh dostarczyły istotnych nowych zbiorów danych pierwotnych, które umożliwiły rozpoznanie procesów uprawy i utowarowienia roślin oraz przyczyniły się do rozszerzenia istniejących baz danych, mogących służyć dalszym badaniom naukowym.

W projekcie zastosowano standardową i optymalną metodę pobierania próbek archeobotanicznych (Wasylikowa 2005). Podstawowy zestaw narzędzi archeobotanicznych obejmuje systematyczne zbieranie pozostałości roślinnych (za pomocą flotacji), sortowanie pod niskim powiększeniem oraz identyfikację przy wykorzystaniu zbiorów porównawczych i atlasów regionalnych. Po wydobyciu próbek pierwszym etapem badań była analiza statystyczna składu zespołów (wskaźnik powszechności, względna częstość występowania i wybrane współczynniki międzygatunkowe). Przetwarzanie plonów oceniono na podstawie ustalonych metod oceny proporcji ziaren, plew i grup nasion chwastów. Wybrane rośliny zostały zmierzone i sfotografowane w celu udokumentowania potencjalnych zmian morfologicznych i morfometrycznych. Na końcowym etapie badania wybrane ziarna zostały poddane analizie stabilnych izotopów ($\delta^{13}C$, $\delta^{15}N$), które pozwalają na identyfikację nawożenia i nawadniania upraw.

Stabilne izotopy węgla ($\delta^{13}C$) i azotu ($\delta^{15}N$) w roślinach zmieniają się w zależności od występujących czynników środowiskowych (Bogaard et al. 2013). Wartości $\delta^{13}C$ roślin są stosowane głównie do badania praktyk gospodarki wodnej w rolnictwie, ponieważ wiadomo, że nawodnienie roślin ma wpływ na skład izotopowy węgla (Fiorentino et al. 2014). Dowiedziono również, że gleby o wysokim stężeniu organicznego azotu – wzbogacone poprzez nawożenie, uprawę przy udziale zwierząt lub naturalnie zasobne – mają wyższy poziom $\delta^{15}N$, co znajduje odzwierciedlenie w materiałach archeobotanicznych (Fiorentino et al. 2014). Obie te metody były szeroko stosowane w badaniach archeologicznych w celu określenia warunków środowiskowych, w jakich rosły rośliny. Choć badania te są powszechnie stosowane w stosunku do zbóż i roślin strączkowych, znacznie rzadziej stosowano je w odniesieniu do roślin wieloletnich. W związku z tym istotna część prezentowanej pracy skupia się na zastosowaniu metod analizy stabilnych izotopów, wcześniej opracowanych dla zbóż i roślin strączkowych, do badania roślin wieloletnich.

Procesy utowarowienia roślin (lub innych dóbr) nie mogą być określone wyłącznie na podstawie artefaktów czy danych bioarcheologicznych. Dlatego kluczowe było osadzenie analiz archeobotanicznych w kontekście archeologicznym – zarówno artifaktowym, architektonicznym, jak i chronologicznym. Zarządzanie zasobami żywnościowymi oraz procesy utowarowienia zostały rozpoznane w kontekście architektonicznym i artifaktowym ich przechowywania. Analizie poddano takie aspekty jak wielkość i lokalizacja przestrzeni magazynowych (prywatne lub publiczne), typ dostępu (swobodny lub ograniczony) oraz towarzyszące przedmioty, takie jak naczynia, pieczęcie i odciski pieczęci (Joka 2025).

4. Materiały

Aby uzyskać kompleksowe zrozumienie fitosfery na badanym stanowisku – obejmujące zarówno cechy morfologiczne wybranych roślin, jak i diachroniczne zmiany w repertuarze upraw – zaleca się analizę zbioru wszystkich prób ze stanowiska. W związku z tym, przed wyborem kontekstów kluczowych dla niniejszej rozprawy doktorskiej, przeprowadzono szczegółową analizę archeobotaniczną wszystkich próbek pochodzących z trzech wspomnianych stanowisk. Obejmowało to 179 próbek z Tel Qedesh, 56 próbek z Gurga Chiya oraz 235 próbek z Kani Shaie. Następnie dokonano starannej selekcji materiału, eliminując próbki mogące potencjalnie zafałszować wyniki badań ze względu na ich niewielkie znaczenie chronologiczne lub kontekstualne. Ostatecznym etapem procesu było wytypowanie próbek przeznaczonych do dalszych badań izotopowych. Poniżej przedstawiono szczegółowy opis materiału wykorzystanego w rozprawie doktorskiej.

Tel Qedesh

Celem analizy próbek z Tel Qedesh była ocena zastosowania analizy stabilnych izotopów (SIA) dla roślin wieloletnich pochodzących z kontekstów archeologicznych. Dobór materiału archeologicznego oparto na nienaruszonych warstwach zawierających nasiona winorośli i oliwki. Ostatecznie do analizy izotopowej wybrano 26 dobrze zachowanych, nieuszkodzonych i całkowicie zwęglonych okazów winorośli (Vitis vinifera, 10 okazów) i oliwki (Olea europaea, 16 okazów) pochodzących z 13 kontekstów w dwóch obszarach stanowiska – fortyfikacji z wczesnej epoki brązu (EB I-II) obejmującej cztery konteksty wtórne oraz osiedla mieszkalnego z EB II obejmującego dziewięć kontekstów pierwotnych. Dodatkowo, do celów porównawczych, włączono sześć współczesnych próbek owoców (trzy próbki winogron i trzy oliwek).

Kani Shaie

Zespół archeobotaniczny zebrany w Kani Shaie umożliwia kontekstualizację procesów utowarowienia roślin. Analizie poddano 14 próbek bogatych w materiał archeobotaniczny (1 204 nasiona i fragmenty nasion, głównie roślin strączkowych i zbóż, z niewielką liczbą chwastów upraw polowych), pochodzących z kontekstów interpretowanych jako część strefy dystrybucji żywności przylegającej do struktury z paleniskiem. W obszarze tym znajdowały się również narzędzia administracyjne, takie jak pieczęcie, służące zarówno do plombowania pojemników z nasionami, jak i drzwi. Materiał ten został poddany analizie archeobotanicznej zgodnie z wcześniej przedstawionym protokołem. Układ architektoniczny i powiązane artefakty wskazują, że przestrzenie te nie miały charakteru domowego, lecz były obszarami o ograniczonym dostępie, przeznaczonymi do magazynowania i dystrybucji żywności.

Gurga Chiya

Analiza próbek z Gurga Chiya miała na celu wniesienie wkładu do dyskusji nad rozwojem rolnictwa i zarządzaniem nadwyżkami żywności jako powiązanymi czynnikami, które wpłynęły na kluczowe zmiany w społeczeństwach mezopotamskich w V tysiącleciu p.n.e. W związku z tym wybrane konteksty były związane z aktywnością magazynowania żywności na stanowisku.

Spośród 21 pierwotnie analizowanych próbek do dalszych badań wybrano 12 próbek pochodzących z magazynów oraz kontekstów związanych z przechowywaniem, należących do zespołu Gurga Chiya z późnego okresu Ubaid. Zespół ten zawierał wyjątkowo dużą liczbę pozostałości archeobotanicznych – łącznie 30 300 nasion (głównie soczewicy i jęczmienia), fragmentów nasion oraz resztek żywności. Dane archeologiczne sugerują, że magazyny należały do indywidualnej jednostki domowej, a w połączeniu z danymi archeobotanicznymi wskazują na dużą niezależność ekonomiczną gospodarstwa domowego. Z materiału archeobotanicznego do dalszej analizy wartości izotopowych $\delta13C$ i $\delta15N$ wybrano 4 nasiona pszenicy samopszy, 7 nasion jęczmienia i 8 soczewicy, pochodzących z 11 kontekstów, a także 3 dodatkowe konteksty z późnoneolitycznych poziomów Tepe Marani (zob. Tabela 2).

5. Wyniki

Procesy utowarowienia roślin miały miejsce w okresie przejściowym między późnym neolitem a wczesną epoką brązu, czyli między uprawami na małą skalę, których celem było zaspokojenie potrzeb lokalnej społeczności, a uprawami inwestycyjnymi wynikającymi ze stabilizacji społeczeństwa i nadwyżek żywnościowych. Analiza materiałów z późnoubaidzkiej osady Gurga Chiya oraz osady z wczesnej epoki brązu w Kani Shaie pozwoliła określić diachroniczną trajektorię procesów utowarowienia oraz umiejscowić je w kontekście społecznym i ekonomicznym – zarówno w odniesieniu do mieszkańców osad, jak i w skali regionalnej. Na późnoubaidzkim stanowisku Gurga Chiya dowody wskazują na przechowywanie plonów rolnych w ilościach przekraczających podstawowe potrzeby pojedynczego gospodarstwa domowego. Nadwyżki te mogły umożliwiać wymianę oraz inne formy współpracy w obrębie społeczności. Co istotne, znaczna ilość soczewicy w porównaniu do zbóż może odzwierciedlać sezonową dostępność plonów lub odmienne zastosowania kulinarne – np. pszenica mogła być przetwarzana na kaszę lub chleb (Carter i in. 2020). Części magazynowe należą do poszczególnych jednostek domowych, co sugeruje rosnącą autonomię gospodarczą dużych rodzin (Carter i Wengrow 2020). Brak odpadów po przetwarzaniu roślin, takich jak łuski czy plewy, w pobliżu magazynów wskazuje, że plony były przetwarzane przed przechowywaniem, prawdopodobnie na zewnątrz budynków. Ten schemat jest zgodny z innymi stanowiskami ubaidzkimi, takimi jak Tell Abada i Kenan Tepe (Jasim 2021; Graham 2011; Graham i Smith 2015). Takie działania wymagały znacznego wysiłku zbiorowego, co sugeruje istnienie wzajemnych porozumień między jednostkami osadniczymi lub udział dużych, wielopokoleniowych rodzin w sezonowych pracach żniwnych (Fuller i Stevens 2009). Dalszym dowodem rosnącej autonomii gospodarstw domowych w okresie ubaidzkim jest brak wyraźnych oznak administracyjnej kontroli nad nadwyżkami. Kontrastuje to z wcześniejszym okresem późnoneolitycznym oraz późniejszymi kontekstami chalkolitycznymi i wczesnobrązowymi, gdzie zarządzanie nadwyżkami było często związane z centralizowaną administracją (Frangipane 2007; Akkerman i Duistermaat 2004). Analiza stabilnych izotopów z Gurga Chiya, porównana z wcześniejszym stanowiskiem późnoneolitycznym Tepe Marani, ujawnia istotne zmiany w praktykach uprawy zbóż. Wyniki te sugerują stopniowe przejście w kierunku bardziej ekstensywnych systemów rolniczych o niższym nakładzie pracy na jednostkę powierzchni w miarę upływu czasu (por. Diffey i in. 2020; Styring, Charles i Fantone 2017). Ta trajektoria rozwoju jest zgodna z szeroko przyjętymi modelami, które przeciwstawiają intensywne rolnictwo późnego neolitu wczesnohistorycznemu procesowi ekstensyfikacji (Styring, Charles i Fantone 2017; Maltas i in. 2022; Diffey i in. 2020). Jednakże, aby dokładniej określić rolę okresu ubaidzkiego w tych przemianach, potrzebne są dodatkowe dane z współczesnych stanowisk, aby uzupełnić luki w zapisach środowiskowych z V tysiąclecia p.n.e. Dowody archeobotaniczne i archeologiczne na wyspecjalizowane magazynowanie w Gurga Chiya stanowią okazję do zbadania wczesnych procesów utowarowienia oraz do ponownej oceny założeń dotyczących późnego okresu ubaidzkiego. Często zakłada się, że wyspecjalizowane magazynowanie i nadwyżki ekonomiczne są ściśle powiązane ze stratyfikacją społeczną i pojawieniem się elit, które wykorzystują nadwyżki do konsolidacji władzy politycznej (Frangipane 2007; Algaze 2008; Stein 2020). Okres ubaidzki jest często postrzegany jako etap przejściowy między egalitarnymi wioskami neolitycznymi a powstawaniem społeczeństw o strukturze państwowej, charakteryzujących się wodzostwami (np. Stein 1994; Algaze 2008; krytycznie: Yoffee 1993). Jednak dowody z wcześniejszych późnoneolitycznych stanowisk (Halaf) w północnej Mezopotamii, takich jak Tell Sabi Abyad

(Akkermans i Duistermaat 1996) oraz Yarim Tepe II (Merpert i Munchaev 1993), podważają pogląd, że nadwyżki żywności nieuchronnie prowadzą do nierówności społecznych (Wengrow 1998). W Gurga Chiya pojawienie się wyspecjalizowanego magazynowania w obrębie pojedynczych gospodarstw domowych zastępuje wcześniejsze wzorce przechowywania wspólnotowego, co wskazuje na zmianę w zarządzaniu nadwyżkami. Chociaż duże gospodarstwa domowe mogły zyskać większą autonomię gospodarczą w późnym okresie ubaidzkim, nie musi to oznaczać istnienia formalnych hierarchii społecznych. Zamiast tego, takie zmiany mogą odzwierciedlać nowe formy współzależności między gospodarstwami, obejmujące skoordynowaną wymianę nadwyżek plonów. Dynamika ta mogła umożliwiać specjalizację rolniczą na poziomie lokalnym, kształtowaną przez specyfikę upraw i mikrośrodowiska, co potwierdzają dane archeobotaniczne z Gurga Chiya

Dane archeologiczne i botaniczne z Kani Shaie dostarczyły cennych informacji na temat komercjalizacji upraw we wczesnej epoce brązu, pozwalając na określenie roli małych ośrodków administracyjnych w procesie utowarowienia zasobów roślinnych – zarówno tych poprzedzających wielkie centra urbanizacji, jak i funkcjonujących poza nimi. Materiał z Kani Shaie pozwala lepiej zrozumieć wczesne procesy komercjalizacji plonów. Odnosząc się do definicji Kopytoffa (1987), utowarowienie polega na przekształceniu przedmiotów w dobra wartości fizycznej lub symbolicznej, odróżniającej je od codziennych produktów, naznaczając je jako towar. W Kani Shaie elementy takie jak spichlerz o ograniczonym dostępie, zaplombowane jednostki magazynowe i precyzyjne porcjowanie plonów wskazują na wczesne formy utowarowienia. Praktyki te nadawały przechowywanym plonom wartość nie tylko jako namacalnym towarom, ale także w ramach systemu redystrybucji.

Choć powyższe cechy sugerują procesy utowarowienia, brak jest bezpośrednich dowodów na handel lub wymianę rynkową. Zamiast tego Kani Shaie zdaje się funkcjonować w ramach modelu scentralizowanej redystrybucji. Nadwyżki rolnicze były gromadzone, przechowywane i rozprowadzane wewnątrz społeczności lub potencjalnie także do grup zewnętrznych. Strategiczne położenie Kani Shaie między górami Zagros a nizinami Mezopotamii podkreśla jego potencjalne znaczenie jako regionalnego ośrodka wymiany. Dowody sięgające V tysiąclecia p.n.e. sugerują, że miejsce to pełniło funkcję centralnego węzła w dolinie Bazyan, prawdopodobnie jako punkt postojowy dla podróżników lub koczowniczych pasterzy przemieszczających się między terenami górskimi a nizinami (Tomé, Cabral i Renette 2016). Ta korzystna lokalizacja mogła wspierać jego rolę w obsłudze mobilnych grup i zarządzaniu nadwyżkami plonów przeznaczonymi do szerszej dystrybucji. Rosnąca skala produkcji rolniczej w Kani Shaie wspiera hipotezę, że systemy scentralizowanej dystrybucji powstały w odpowiedzi na nagromadzenie nadwyżek. Obecność pieczęci, odcisków pieczęci i magazynów o ograniczonym dostępie dodatkowo wskazuje na środki służące monitorowaniu i zarządzaniu przepływem dóbr, co wzmacnia rolę tego miejsca w zorganizowanym systemie redystrybucji. System ten prawdopodobnie wspierał nie tylko lokalną społeczność, ale także grupy mobilne lub wyspecjalizowane, takie jak rzemieślnicy i kupcy, co podkreśla wieloaspektową rolę osad wiejskich w szerszych sieciach gospodarczych (Schwartz 2015; Frangipane 2007). Przykład Kani Shaie ilustruje, że procesy takie jak centralizacja i utowarowienie nie były ograniczone do ośrodków miejskich. Dowody na zarządzanie nadwyżkami, redystrybucję i praktyki administracyjne w tej niewielkiej osadzie wiejskiej podważają tradycyjne poglądy, które przypisują te cechy wyłącznie urbanizacji (Graeber i Wengrow 2022). Stanowisko to podkreśla różnorodne ścieżki prowadzące do złożoności społecznej we wczesnej epoce brązu w Mezopotamii. Odkrycia z Kani Shaie przyczyniają się do rosnącego korpusu badań wskazujących, w jaki sposób produkcja rolnicza i zarządzanie zasobami stanowiły kluczowe fundamenty dla rozwoju złożonych społeczeństw. Analizując te procesy na różnych stanowiskach i w osadach o różnej wielkości, możemy uzyskać bardziej zniuansowane zrozumienie początków urbanizacji i powstawania elementów powszechnie kojarzonych ze społeczeństwami złożonymi. Wyniki badań z Gurga Chiya i Kani Shaie sugerują, że utowarowienie roślin było procesem stopniowym i w obu przypadkach odzwierciedlało szerszy system gospodarczy. Podsumowanie badań obu osad ukazuje złożoność mechanizmów utowarowienia roślin. Z perspektywy diachronicznej można dostrzec przejście od dystrybucji żywności na małą skalę w społecznościach neolitycznych, przez prywatne zapasy należące do rozległych gospodarstw domowych, aż po kompleksy magazynowe prawdopodobnie zarządzane centralnie i rozdzielające zapasy w obrębie większej społeczności. Zarówno początek procesów utowarowienia, jak i precyzyjne określenie momentu, w którym rośliny stały się towarem, pozostają kwestiami spornymi. Jednak stopniowe zmiany w kierunku utowarowienia są dostrzegalne i mogą być potwierdzone zarówno archeologicznie, jak i poprzez badania archeobotaniczne.

Ważnym, ale w dużej mierze pomijanym czynnikiem w trajektoriach złożoności społecznej jest uprawa i utowarowienie roślin wieloletnich. Pojawienie się upraw wieloletnich stanowiło istotną zmianę w użytkowaniu ziemi w przeszłości, wymagającą długoterminowych inwestycji w grunt oraz przekształcenia i utowarowienia określonych upraw. Sugeruje się, że ten rozwój był ściśle związany z urbanizacją i rosnącą złożonością społeczną w niektórych częściach

Eurazji. Niektórzy badacze wskazują na możliwość, że komercjalizacja upraw owocowych i specjalizacja w zakresie produktów wtórnych pochodzenia zwierzęcego rozwijały się równolegle w wielu społeczeństwach eurazjatyckich (Mccoriston, 1997; Sherratt, 1999; Fuller i Stevens, 2019) i są częścią zjawiska rolnictwa inwestycyjnego. W tym kontekście rola roślin wieloletnich w kształtowaniu organizacji administracyjnej wczesnych państw i urbanizacji jest porównywalna z rolą rzemiosł, takich jak produkcja tekstyliów, kamieniarstwo i metalurgia. Jednak procesy związane z zarządzaniem i przekształcaniem upraw owoców wieloletnich – od niewielkich przydomowych ogrodów po wielkoskalowe sady znane z epoki brązu – pozostają słabo zbadane.

Na obszarze Azji Południowo-Zachodniej najwcześniejsze przypadki udomowienia drzew, które były zarówno poprzedzone, jak i towarzyszyła im uprawa, miały miejsce prawdopodobnie między 6500 a 3500 r. p.n.e., co potwierdzają analizy morfologiczne i morfometryczne archeobotanicznych makroszczątków (Fuller i Stevens, 2019). W tym okresie produkcja zarówno rocznych, jak i wieloletnich upraw rolniczych systematycznie rosła, a wiele upraw zostało przekształconych w szeroko handlowane towary. Podczas gdy ekstensyfikacja upraw zbóż została powiązana z powstaniem najwcześniejszych miast w zachodniej Azji (Styring et al., 2017), rola arborystyki w tym procesie pozostaje niedostatecznie zbadana, a jest ona istotna dla zrozumienia wymiany produktów rolnych, organizacji produkcji i ich powiązań z wczesnym rozwojem miast w regionie (Fuller i Stevens, 2019). W rezultacie większość naszej wiedzy na temat technik sadowniczych pochodzi z okresów historycznych, kiedy te uprawy były już integralną częścią gospodarki rolnej (Childe, 1950; Renfrew, 1973; Miller i Wetterstrom, 2000; Weiss, 2015; Fuller i Stevens, 2019). J ednym z metodologicznych podejść umożliwiających wgląd w zarządzanie roślinami wieloletnimi – a które wykazało ogromny potencjał w badaniach nad dawnym gospodarowaniem udomowionymi zbożami i roślinami strączkowymi – jest analiza stabilnych izotopów węgla i azotu w zwęglonych szczątkach roślin. Aby zbadać potencjał analiz stabilnych izotopów w badaniu zarządzania roślinami wieloletnimi w przeszłości, zastosowałam oznaczenia stabilnych izotopów węgla ($\delta^{13}C$) i azotu ($\delta^{15}N$) do starożytnych oliwek (*Olea europaea L.*) i winogron (*Vitis vinifera L.*) pochodzących ze stanowiska archeologicznego Tel Qedesh, położonego w Górnej Galilei w Izraelu.

W ramach moich badań oceniłam (i) przydatność metod analizy stabilnych izotopów, które zostały wcześniej opracowane dla roślin jednorocznych, do badania roślin wieloletnich oraz (ii) potencjalne możliwości i ograniczenia wspomnianych metod w badaniach nad praktykami uprawy roślin wieloletnich w społeczeństwach starożytnego Lewantu.

6. Wpływ doktoratu na rozwój dziedziny

Przedstawiona rozprawa doktorska podsumowuje jakkolwiek ograniczoną wiedzę na temat uprawy roślin i komodyfikacji w okresie tzw. późnej prehistorii, jednocześnie definiując nowe ramy teoretyczne dla tego zagadnienia. Opracowane definicje mechanizmów komodyfikacji są oparte na badaniach empirycznych – zarówno archeologicznych, jak i archeobotanicznych – przeprowadzonych na stanowiskach archeologicznych w Azji Południowo-Zachodniej. Praca ta oferuje pierwszy istotny wgląd w wcześniej pomijane mechanizmy komodyfikacji upraw: ich odzwierciedlenie i powiązania z rzeczywistościami społeczno-ekonomicznymi, a także wpływ komodyfikacji roślin na kształtowanie kultur i rozwój kompleksowości społecznej. Oprócz dobrze opracowanej podstawy teoretycznej, kolejnym kluczowym aspektem przedstawionej pracy są zastosowane metody eksperymentalne. Jednym z celów tej rozprawy doktorskiej było rozpoznanie praktyk rolniczych, ponieważ efektywność produkcji żywności była uznawana za jeden z głównych czynników napędzających wzrost złożoności społecznej. W tym celu zastosowano nowoczesne narzędzia do rozpoznawania dawnych metod upraw roślin, w tym analizy izotopów stabilnych, które przeprowadzono zarówno w tradycyjnej formie (na zbożach i roślinach strączkowych), jak i w formie eksperymentalnej (na roślinach wieloletnich). Jest to pierwszy krok w kierunku lepszego zrozumienia metod uprawy roślin wieloletnich, który również wnosi istotny wkład w rozwój technik analizy izotopów stabilnych w badaniach archeobotanicznych. Opracowane w pracy aspekty metodologiczne i teoretyczne mają charakter uniwersalny i mogą być dostosowane do badań archeologicznych niezależnie od epoki czy regionu. Tymczasem wyniki pochodzące z analizowanych przypadków przyczyniają się do naszego zrozumienia upraw roślin i komodyfikacji w Azji Południowo-Zachodniej. Niemniej jednak rozprawa doktorska nie wyczerpuje w pełni tematu komodyfikacji roślin i jej znaczenia kulturowego. Jest to szeroki i wciąż niedostatecznie zbadany temat, który wymaga znacznie większej uwagi, niż mogłam poświęcić mu w ramach niniejszej dysertacji.

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Exploring the potential of stable carbon and nitrogen isotope analysis of perennial plants from archaeological sites: A case study of olive pits and grape pips from Early Bronze Age Qedesh in the Galilee

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ABSTRACT

The emergence of perennial fruit cultivation represents a potentially important change in land use in the past, being associated with long-term investments in land and the transformation and commodification of particular crop products. Indeed, it has even been argued to have been closely linked to urbanization and social stratification in parts of Eurasia. Olives (*Olea europea*) and grapes (*Vitis vinifera*) were among the first and most popular of the fruit cultivars (Early Chalcolithic) and commodities (by Early Bronze Age), however, the cultivation practices used to manage these crops remain fairly poorly-understood prior to evidence from the historical record. In this study we seek to determine the applicability of stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope analysis to perennial plant remains using archaeobotanical remains of olives and grapes from the Early Bronze Age site of Tel Qedesh in Israel. For grapes, we provide the first archaeobotanical $\delta^{13}C$ values for this crop, necessitating further study development for more in-depth interpretation. Meanwhile, we plot our olive values against an existing dataset to show that the plants from Tel Qedesh appear to have been efficiently hydrated. Our attempts at $\delta^{15}N$ analysis for grape and olive remains did not yield satisfactory results, highlighting the need for future methodological development. We present a comprehensive plan for the development of a methodological framework and interpretative model for perennial plants, based on the models previously applied for the investigation of cereals and pulses. We argue that recognition of the past cultivation methods of perennial plants is crucial for better understanding agricultural changes and their role in key socioeconomic transitions in the past.

1. Introduction

In Southwest Asia, the temporal gap between the emergence of agriculture, here defined as the organized formation of arable fields and economic reliance on cultivated crops, and the first cities is significant, and amounts to about 5,000 years (Fuller and Stevens, 2019). Food surpluses, which resulted from cereal-based agricultural systems, have traditionally been associated with an increase in population and settlement growth (Bocquet-Appel, 2011; Childe, 1950). The socioeconomic consequences of scaling up agricultural production have also been suggested to have catalyzed labour differentiation and professionalization in craft production, administration, trade, as well as further agricultural developments, including the beginnings of the cultivation of perennial plants (Bocquet-Appel, 2011; Fuller and Stevens, 2019). An expanded cultivation of perennial plants, especially fruit trees and shrubs, can be seen as an element of crop extensification, which involves the shift from small-scale, intensively cultivated crops to large scale production (in terms of acreage) but with lower labour input (Styring,Charles,and Fantone, 2017). Some researchers indicate the possibility that fruit crop commodification and specialization in animal secondary products emerged in parallel in many Eurasian societies (Mccoriston, 1997; Sherratt, 1999; Fuller and Stevens, 2019), and are

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part of *investment agriculture* phenomenon: a form of land use which relied on longer term labour input with an acceptance of prolonged period of growth before harvest and profiting (Sherratt, 1999; Fuller and Stevens, 2019). As such, perennial fruit plants have been argued to have acted as a trigger for the development of land ownership rights and social stratification (Renfrew 1972; Sherratt, 1999).

In this regard, the role of perennial plants in shaping the organizational administration of early states and urbanism is arguably comparable to the role of craft specialties such as textile production, masonry or metallurgy, at least in some contexts (Fuller and Stevens, 2019). Unfortunately, the mechanisms accompanying the management and transformation of perennial fruit crops, from small home gardens to large-scale crop fields known from the Bronze Age, have not yet been thoroughly recognized. In Southwest Asia the earliest arboreal domestication, preceded and accompanied by cultivation, most likely occurred between 6,500 BCE – 3,500 BCE as evidenced by the morphological and morphometrical data of archaeobotanical macroremains (Fuller and Stevens, 2019). During this period, the production of agricultural crops - both annual and perennial – was gradually increased, and crops were transformed into commodities which came to be traded widely. It has been argued that extensification of cereal agriculture drove the emergence of the earliest cities in western Asia. (Styring et al., 2017) However, the entire branch of agriculture of arborical production has been almost entirely overlooked in this regard, despite its significance to studies of crop product exchange and production organization and their relationship to the potential emergence of urbanism in western Asia (Fuller and Stevens, 2019). As a result, our knowledge of arboricultural techniques comes mainly from historical times, where these crops already played a key role in agricultural industry (Childe, 1950; Renfrew 1973, Miller and Wetterstrom, 2000; Weiss, 2015; Fuller and Stevens, 2019).

One methodological approach for delving deeper in time in the search for insights into perennial management, that has shown immense promise for studying the past management of domesticated cereals and legumes, is stable carbon and nitrogen isotope analysis of charred plant remains (Fiorentino et al., 2014). While stable carbon isotope analysis is considered to track the water conditioning of past plants, stable nitrogen isotope analysis is thought to be reflective of soil conditions, including manuring (Fraser et al., 2013; Wallace et al., 2013). Although rarely applied to perennial plants to date, Ehrlich et al. (2022) performed a pilot study of stable carbon isotope analysis of ancient olive pits, which allowed them to infer the environmental conditions experienced by olive trees growing over a time span of ~ 6,000 years in the area of modern-day Israel. In this paper, we seek to expand this promising work by studying perennial plant remains from Tel Qedesh, a large Early Bronze Age hub in the Galilee region in Israel (Wachtel and Davidovich, 2021). The site is located on the western side of a ca. 7 km^2 fertile valley (Qedesh Valley) and is identified with the biblical town of "Qedesh in the Galilee" (Joshua 20, 7). The remains of two fruit species, olive (*Olea europea*) and grape (*Vitis vinifera*) have been recorded in Early Bronze Age layers of the site.

In order to investigate the potential of stable isotope analyses to explore the management of perennial plants in the past, we apply stable carbon (δ^{13}C) and nitrogen (δ^{15}N) isotope determinations to the ancient olives (*Olea europea* L.) and grapes (*Vitis vinifera* L.) from Tel Qedesh. We evaluate (i) the applicability of stable isotope analytical methods previously developed for annually grown plants for the study of perennial plants and (ii) the recognition of potential opportunities and limitations of the above-mentioned methods in the study of perennial crop cultivation practices among past societies in the Levant. We also present a detailed plan for the development of an interpretative model for perennial plants, based on the models previously applied for the investigation of past cultivation methods of cereals and pulses (vide Wallace et al., 2013; Charles et al., 2002; Charles and Hopp, 2003; Bogaard and Jones, 2007; Fraser et al., 2011; Bogaard et al., 2013; Stroud,Bogaard, and Charles, 2021; Nayak et al., 2022; Maltas et al., 2022), and suggest how the existing interpretative framework for δ^{13}C values of olive pits could be developed for the interpretation of cultivation methods. Although existing work focused on olive archaeobotanical remains as an indicator of paleoenvironmental changes, (Ehrlich et al., 2022), the model presented as a result of this project can be used as an initial benchmark for assessing the general water status of olive trees in the ancient Levant.

2. Historical and archaeological sources for olive and grape cultivation

The domesticated olive, originating from its wild progenitor (*Olea europea* L. ssp. *Oleaster*) is historically one of the most important Mediterranean cash crops, and its commercial potential was already apparently established during the Early Bronze Age (Weiss, 2015). Wild oleasters are a characteristic part of the Mediterranean biome, with genetic studies suggesting that the northern Levant was the primary centre of olive domestication (Kaniewski et al., 2012), while the earliest evidence of olive tree cultivation outside of their natural range so far comes from the Central Jordan Valley at Tel Tsaf (5200-4700 BCE) (Langgut and Garfinkel, 2022). Numerous archaeological finds suggest that olive tree cultivation was preceded by the production and consumption of olive oil (evident from f.e Late Pottery Neolithic/Early Chalcolithic Kfar Samir on the Northern Israeli coast, or contemporary Ain Zippori in Lower Galilee) (Namdar et al., 2015), and then by table olives (evident in e.g., Middle Chalcolithic layers of Hishuley Carmel, also by the Northern Israeli coast) (Galili et al., 2021).

It is generally agreed that the cultivation and processing of olives was widespread in the Southern Levant by 6000 cal. BP, based on the findings from Rasam Harbush (Golan Heights), Abu Hamid and Tell es Shuna (Jordan valley), and Teleilat Ghassul (lower Jordan valley) (Liphschitz et al., 1991; Spoor, 2001; Langgut et al., 2014; Langgut and Garfinkel, 2022; Barazani,Dag,and Dunseth, 2023). Based on charred plant remains from 47 Israeli archaeological sites, Liphschitz (1991) found that the proportion of olive tree remains increased from 20 to 30 % during the Chalcolithic to 40–60 % during the Early Bronze Age (in a time span of ca. 1200 years, 5300–4100 BP). Cultivation then enabled the growing of olive trees beyond their natural habitat, at various latitudes and in more arid areas (Langgut and Garfinkel, 2022). Considering the biological requirements of olives (the tree requires at least 400 mm of annual rainfall), olive trees cultivated in the Jordan Valley could be either rainfed or additionally irrigated (Langgut and Garfinkel, 2022), and perhaps cut/pruned in order to increase fruit production. Olives became a cash crop by the Early Bronze Age, as evident at Tel Yarmouth (Palestine) (Salavert, 2008), and olives subsequently became one of the most popular commodities by the Iron Age (Kaniewski et al., 2012), as evident from the archaeological records of the Levant, Egypt, Mesopotamia and Mediterranean basin regions (Greenberg, 2011; Barazani, Dag,and Dunseth, 2023).

Grapevine (*Vitis vinifera* L.) is another major horticultural crop, whose cultivation had a potentially major impact on the development and dynamics of early urban settlements in Southwest Asia (Weiss, 2015). Grape fruits are nutritious and palatable, and can be eaten fresh or dried and pressed for juice, later rendered into wine (Weiss,Zohary, and Hopf, 2012). The potential of grape products lies in their durability, ease of storage and transportation, and these features made grapes one of the most popular cash crops in the antiquity (Weiss,Zohary,and Hopf, 2012). Grape remains, prior to domestication and cultivation (*Vitis vinifera* ssp. *Silvestris*), have been found in the archaeological contexts of the Mediterranean basin, Southwest Asia and the Caucasus dating back to early prehistoric times (f.e Harutyunyan, Malfeito – (Harutyunyan and Malfeito-Ferreira, 2022; Hovsepyan and Willcox, 2008; Weiss, 2015; Taskesenlioglu et al., 2022). The remains of grape seeds were found in Chalcolithic levels of the cave complex of Areni −1 (Armenia), along with a winepress installation and ceramic vessels used to store wine which provide the earliest evidence of cultivation and processing of the grapevine (ca. 6000 BP) (Barnard et al., 2011; Areshian et al., 2012). Yet some of the earliest probable domesticated grapevine remains come from several Early Bronze Age sites in the Levant, such as EBA layers of Jericho, Lachish and Arad (Israel), and Tell es-Sa'idiyeh (Jordan) (Weiss, 2015; Nicolì et al., 2022). Bearing in mind that the vine is a very water demanding crop (635 to 890 mm, annually) it is probable that the above-mentioned finds were additionally irrigated and pruned as a part of cultivation necessary in the semi-arid climate of Jordan valley.

Early historical texts assist in our understanding of the origins of large-scale perennial farming. The textual evidence for grapevine and olive by-product processing and trade are extensive for Southwest Asia, North Africa and the Mediterranean basin, though there is a limited amount of ancient historical sources from the area which describe cultivation methods. In the Bible there are descriptions of orchards, mentioning olive grafting, preparation of vineyards and grapevine pruning, as well as fig tree manuring (Is 5,1 – 5,7; Lu 13, 6 – 13,9; Deut 6, 11), and an extensive text describing (among others) the cultivation of many species of perennials (olives, grapes, figs, pomegranates, apples, etc.) is *Historia Plantarum* by Theophrastus (ca.350—287 BCE) (after French, 1994). Magos' of Carthage texts on viticulture (ca. 3rd-2nd BC, based on Roman copies, as the original Punic texts have been lost) and Marcus Porcius Cato the Elder (c. 234–149 BCE), are describing specifically cultivation of olives and vines (after Reynolds, 2017). Lin Foxhall (2009) has comprehensively outlined the details of olive tree cultivation (often comparing them to other Mediterranean orchards, such as grapes), pointing to the variety of cultivation methods used in Greece alone, such as controlled channel irrigation, manure or other organic fertilizer usage for the growth, as well as cutting and grafting for controlled propagation. Her research proves that fruit tree cultivation was diversified in methods and intensity in order to maintain crop sustainability. The methods varied depending on biological (local microclimate), but also cultural practices (for example the aim of the cultivation: garden as leisure, or industrial for profit; kind of manure used etc.).

3. Stable isotopes analysis in archaeobotanical research

Over the last ten years, research into past cultivation practices has benefited significantly from advances in stable nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) isotope analysis of preserved archaeobotanical remains (Ferrio et al., 2005; Fraser et al., 2011; Bogaard et al., 2013; Wallace et al., 2013; Fiorentino et al., 2014; Wallace et al., 2015; Stroud, Bogaard,and Charles, 2021). The $\delta^{13}C$ values of terrestrial plant tissues strongly depend on the enzymes that plants use to biologically fix atmospheric CO_2 during photosynthesis. Species with C_3 type methabolism, which account for most crops, use ribulose-1,5-bisphosphate carboxylase-oxygenase (Rubisco) as the primary enzyme. Rubisco discriminates against ^{13}C, since it has intrinsically lower reactivity to ^{13}C compared with ^{12}C (Farquhar et al. 1989). As a consequence, the carbon isotopic signature in plant tissues is lower than that in the atmospheric CO_2 and, as $\delta^{13}C$ in atmospheric CO_2 is relatively stable, the carbon isotopic signature of plant tissues is a good indicator of their photosynthetic activity (Santesteban et al. 2015). Specifically, when the stomata are relatively open (typically when plants are well-watered), there is relatively larger fractionation against ^{13}C, and when they experience water deficit, stomata close, and the isotopic discrimination effect is reduced as the relative proportion of intra-leaf $^{13}CO_2$ increases. Therefore, it is frequently observed that tissues from C_3 plants that have been subjected to water deficit show higher $\delta^{13}C$ than those from non-water stressed plants (Cernusak et al, 2013). The water status of C_3 archaeological grains can be affected either naturally (rainfall, floodings etc.) or anthropologically, by agricultural strategies, such as irrigation, aimed at preventing water stress, interpreted within a particular environmental context (Wallace et al., 2013; Wallace et al., 2015).

Concerning N isotope discrimination, plant uptake is known not to induce significant fractionation during the absorption process, and only under higher nutrient concentration, some can occur (Billy et al., 2010). Therefore, crop $\delta^{15}N$ values reflect the soil nitrogen composition during crop growth. Crop $\delta^{15}N$ values may be influenced by a range of factors (f. e. aridity)(Styring et al., 2017). Application of fertilizers (animal manure, household waste etc.) can increase $\delta^{15}N$ values of soil and cereals by up to 5–10 ‰ (Styring 2017 et al.), and seabird guano even up to 20 ‰ (Szpak et al., 2012).

In order to successfully interpret stable carbon and nitrogen measurements of archaeobotanical remains, a number of long-term experiments and ethnobotanical research on modern crops have been conducted (for example for water management: Charles and Hopp, 2003; Ferrio et al., 2005; for manuring: Bogaard and Jones, 2007; Fraser et al., 2011; Szpak et al., 2012; Bogaard et al., 2013). Wallace et al. (2013) have developed an irrigation transect in Aleppo, Syria for common wheat, to document the stable carbon isotope variability in wheat between unirrigated, moderately irrigated and fully irrigated crops on both manured and unmanured fields. The controlled Syrian experiments have been supplemented by studies from contemporary farms from different areas (northern Spain, greek island Evvia, and region of Wadi ibn Hammad in Jordan) with various regimes practiced (Wallace et al., 2013; Jones, 2005; Araus et al., 1997). Wallace et al. (2013) has summarized this research by presenting the framework for the interpretation of archaeobotanical $\delta^{13}C$ values in terms of water availability for barley, wheat and lentils in the Mediterranean and Southwest Asia. A similar framework has been developed by Bogaard et al. (2013) with regards to stable nitrogen isotope analysis and its relationship to different degrees of manuring (Bogaard et. al. 2007; Fraser et al., 2011).

A range of experiments have also been conducted to specify and recognize the effects of charring and minimize post-depositional contamination of archaeobotanical remains. Nitsch et al. (2015) calculated a charring offset for $\delta^{13}C$ and $\delta^{15}N$ in wheat, (emmer, einkorn, bread wheat) barley, lentil and pea, and Stroud (2023) followed with the procedure for rye and oat. Vaiglova et al. (2014) researched the impact of contamination on stable carbon and nitrogen isotopic composition for charred plant remains, and proposed a range of pre-treatment solutions in order to minimize or remove the post-depositional defiles. Successful applications of presented methods of past cultivation recognition in various projects (for example Bogaard et al., 2013; Styring,Charles,and Fantone, 2017; Stroud,Bogaard,and Charles, 2021; Maltas et al., 2022; Nayak et al., 2022) encourages further experimentation in this field. Finally, Ehrlich et al. (2022) conducted an experiment to recognize the effect of charring on the $\delta^{13}C$ stable isotopes composition of olive pits, and established that, regardless of temperature, charring does not affect the stable isotopic composition significantly relative to olive pit cellulose (less than 1 ‰).

In this paper, we seek to further extend the application of these methods to perennial crops. While most existing studies of the $\delta^{13}C$ and $\delta^{15}N$ values of crops have been applied to cereals, some recent work has already extended this to olives. Ehrlich et al. (2022) applied stable carbon isotope analysis to ancient olive pits from an archaeological site in Israel in order to investigate the environmental conditions of olive growth across a time span of ~ 6000 years. Given that Ehrlich et al. (2022) focused on olive archaeobotanical remains as an indicator of paleoenvironmental changes, the model presented can be used as an initial benchmark for assessing the water status of olive trees in ancient Levant. Here, we expand this initial work by undertaking simple charring experiment on olive pits and grape seeds to explore the possibility of obtaining $\delta^{13}C$ and $\delta^{15}N$ values from both modern and ancient olive pits and ancient grape seeds.

4. Materials and methods

4.1. Archaeological samples

Assessment and analysis of archaeobotanical samples follows the standard procedures established for the Tel Qedesh project. The totality of plant material recovered from soil samples by flotation have been sorted under low power binocular microscope and identified using a reference collection held at the Archaeobotanical Lab at Institute of Archaeology, University College London, UK. A total number of 26 well-preserved, undamaged charred remains of grapes (*Vitis vinifera*) (10 specimens) and olives (*Olea europea*) (16 specimens) from 13 contexts of two areas dated to the Early Bronze Age: an EB I-II fortification (4 secondary contexts) and EB II residential area (9 primary contexts) have been selected for further isotopic research. Two radiocarbon dated contexts from the EB II residential area have been selected for plotting against comparable isotopic data presented in Ehrlich et al. (2022). The details on contexts and chronology of chosen specimens are outlined in the supplementary materials, appendix 1.

4.2. Modern samples

Modern samples of olives were collected from a single tree located in Mount Herzl in Western Jerusalem, Israel, while modern grape samples have been purchased from certified organic farm from Murcia region, Southwestern Spain. Where relevant, the necessary permits were obtained for these collections and analyses. Three categories of samples have been examined for both species: fruit flesh, fruit seed, and whole fruit (flesh + seed were not separated prior to experiment). Grape seeds and whole grape berries has been placed in preheated oven, then charred at 310 °C (the seeds were charred but not ashen), following the suggestion from Ucchesu et al. (2016), where grape seeds charred in temperature between 290 and 310 °C, showed *homogeneous carbonisation and no protrusions or deformations were generated* (Ucchesu et al. 2016). As for the whole grape berries and fruit flesh, the same temperature and conditions has been applied, until the skin on grapes has ruptured, showing the the 'pulp', similarly to Margaritis et al. (2006) experiments results. Olive seeds, whole olives and olive flesh have been charred at 310 °C, so the seed sample as well as fruit tissues have been charred but not ashed (Braadbaar et al. 2016). All the samples were wrapped separately in tin foil and buried in sand throughout the process.

4.3. Fourier transform Infrared spectrometry (FTIR)

Infrared (IR) absorbance spectra were used (following Vaiglova et al., 2014) to identify 1) changes in the composition of seeds (olives & grapes) associated with charring, 2) exogenous contaminants in ancient seeds, and 3) removal of contaminants from seeds during pretreatment for stable isotope analysis. We considered IR spectra from 6 ancient seeds (olive n = 4, grape n = 2), 2 seeds from recent deposits (both olives), and 2 fresh seeds (1 each of olive and grape). For 2 ancient olive seeds, we recorded IR spectra both before and after acid-only pretreatment (suggested in Vaiglova et al., 2014). For the 2 fresh seeds, we recorded IR spectra both before and after charring at 300 °C for 3 h. Due to the large size of the seeds, it was possible to process each seed individually. The detailed description for FTIR results is to be found in Supplementary data.

4.4. Stable $\delta^{13}C$ and $\delta^{15}N$ analysis

Stable isotope analysis was conducted using a Thermo Fisher Scientific Flash Elemental Analyzer coupled to a Thermo Fisher Scientific Delta V Isotope Ratio Mass Spectrometer via a ConFloIV system at the Max Planck Institute of Geoanthropology. A two-point calibration was performed using measurements of international standard reference materials, USGS40 ($\delta^{13}C$ = -26.4 ‰±0.04 ‰, $\delta^{15}N$ = -4.5 ‰±0.1 ‰), IAEA N2 ($\delta^{15}N_{true}$ = 20.3 ‰±0.2 ‰) and IAEA C6, ($\delta^{13}C$ = -10.5 ‰±0.0 ‰). USGS61 ($\delta^{13}C$ = -35.05 ‰±0.04 ‰, $\delta^{15}N$ = -2.87 ‰±0.04 ‰) and UREA ($\delta^{13}C$ = -41.3 ‰, $\delta^{15}N$ = -0.32 ‰) were run as in-house standards. Replicate analyses of the analytical standards suggest that machine measurement error is c. ± 0.37 ‰ for $\delta^{13}C$ and ± 0.37 ‰ for $\delta^{15}N$. The isotopic discrimination of plants against 13C ($\delta^{13}C$) is defined in terms of plant $\delta^{13}C$ sample ($\delta^{13}C$plant), and the $\delta^{13}C$ of atmospheric CO2 ($\delta^{13}C$air) (Farquhar and Richards, 1984). Therefore, values of $\Delta^{13}C$ are comparable across different periods of time and varying $\delta^{13}C$ values of atmospheric CO_2 as the plant sample is compared to its contemporary $\delta^{13}C$air Of note is, that on the contrary of $\delta^{13}C$ plant which is negative, $\Delta^{13}C$ values are positive. $\delta^{13}C$ values were converted into $\Delta^{13}C$ values to allow comparison with modern data, following the Farquhar et al. (1982) equation:

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

Then $\Delta^{13}C$ values were calculated from the determined $\delta^{13}C$ values ($\delta^{13}C$plant) and a $\delta^{13}C$air value approximated by the AIRCO2_LOESS system (Ferrio et al., 2005).

5. Results

5.1. Δ13C analysis

Performed experiment shown that the methods of analysing $\delta^{13}C$plant stable isotope previously applied for the study of annual crops are transferable to perennial plants material. The $\Delta^{13}C$ values for grape pips and olive stones are displayed in Fig. 1.

Ehrlich et al. (2022), using modern olive experiments with well-documented environmental conditions, determined a $\Delta^{13}C$ threshold value of ca. 15.5 ± 0.5 ‰ for olive pits as reflecting arid conditions, while higher $\Delta^{13}C$ values indicate optimal growing conditions. Following the results of Ehrlich et al. (2022) the EBA II period (from which the discussed olive remains are coming from) has been identified as more arid, which is reflected in the lower mean $\Delta^{13}C$ values of olive pits from various archaeological sites (Ehrlich et al., 2022). For the Tel Qedesh olives, $\Delta^{13}C$ values range between 15.1 ‰ up to 23.9 ‰ (mean = 17.2 ‰, standard deviation = 1.4 ‰). These results indicate optimal environmental conditions at the time of growth, which is within the range of results from other archaeological sites of the same period and yearly precipitation values (500 – 600 mm) presented in Ehrlich et al. (2022).

The presented $\Delta^{13}C$ values for grapes range from 18.1 ‰ to 22.1 ‰ (mean = 20.8 ‰, standard deviation = 1.3 ‰) and are generally higher than any mean values recorded for other types of plants, such as cereals (wheat, barley) or legumes (lentil, broad bean), based on Wallace et al. (2013), as well as olives published by Ehrlich et al. (2022). Modern studies indicate that grapes have high drought tolerance, and usually the formation of the fruit occurs during to the dry summer months in these regions, where precipitation is usually scarce (Brillante et al., 2020). Resilience to water stress should be mirrored in the stable isotope composition, hence drought-resistant barley shows higher $\Delta^{13}C$ values when watered, than drought-sensitive wheat grains grown under the same conditions (Wallace et al., 2013). Therefore, it might be expected that grapes will show higher $\Delta^{13}C$ values than more drought sensitive plants cultivated in the same habitat. Potentially, the grape may be highly sensitive to water input, which would also be reflected in the isotopic composition – such a sensitivity is characteristic for legumes, for example, which tend to appear 'wetter' in wet environments, and 'drier' in dry environments compared to cereals (Wallace et.al., 2013).

5.2. $\delta^{15}N$ analysis

Unfortunately, none of the olive or grape samples contained a nitrogen content abundant enough to obtain a readable nitrogen value on the instruments used in this study. This observation is explained by the nitrogen metabolism of fruits, as nitrogen comes from the protein components of plants, which are not very abundant in fruit stones/pipes (samples were comprised of 0.3 to 1.5 % nitrogen compared to 50 to 75

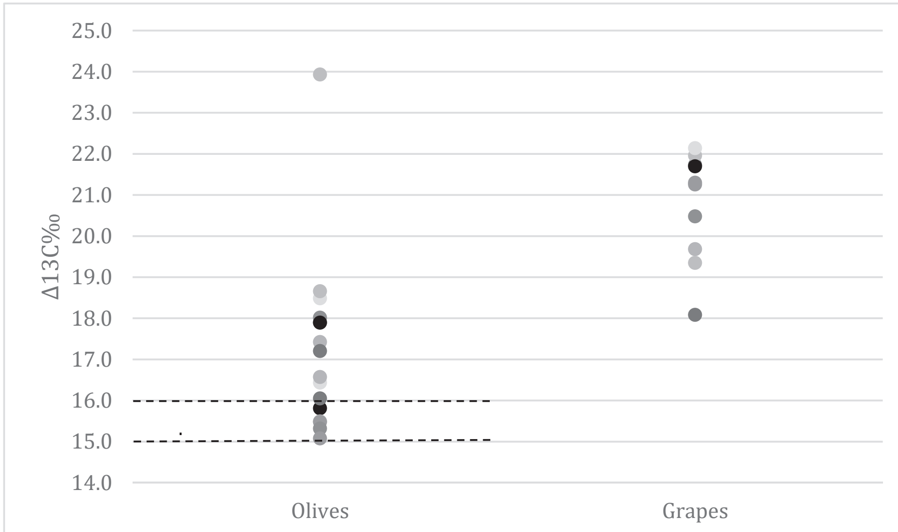

Fig. 1. Plot of Δ13C values of olives and grape remains from archaeological contexts. Dashed lines indicating threshold value for olive pits reflecting arid conditions (low values) and optimal conditions (high values) of olive growth, based on analysis presented in Ehrlich et al. (2022).

% carbon) (Walker et al., 2011; Famiani et al., 2012, 2020). Further explanations on the potential biological and methodological factors affecting the nitrogen content of plant debris are provided in the *Discussion* section.

6. Discussion

Altough the interpretive framework for olive pits currently includes only rainfed specimens, requiring supplementation from isotopic data derived from cultivated olives in the future, it is possible to contextualize Tel Qedesh Δ^{13}C data, with other Early Bronze Age sites (Fig. 2). Combining the results from both wetter and drier periods,[1] it can be concluded that Qedesh olive trees were likely well-hydrated, which could be the result of favorable surroundings, farming practices, or both. Howecer there is no direct evidence for any additional irrigation, other methods of increasing crop efficiency, such as weeding and pruning, cannot be ruled out. It is possible that inhabitants of Tel Qedesh deliberately took advantage of the terrain, placing their orchards on a slight slope and deep soil area where the crops could have access to sufficient water reserves, developing deep root systems, and would simultaneously avoid exposure to current cold conditions characteristic for the bottom of the valley during the winter.

It is currently difficult to study past cultivation strategies due to the lack of an interpretation framework for grapevine Δ13C and the lack of comparable data. However, with the promising results of applying stable isotope analysis methods to modern grapes, creating such a framework shall remain only the matter of time and resources.

There also have been successful trials in obtaining δ^{15}N values from modern olives and grapes, in order to assess the difference between organic and synthetic fertilizers via isotope composition of nitrogen (olive leaves and drupes) (Benincasa,Pellegrino,and Perri, 2018), and to evaluate the effect of terroir on δ^{13}C and δ^{15}N isotope values (grape fruits) (Santesteban et al., 2012). This encourages further research on stable isotopes analysis application to determine the growing conditions of perennial plants, which should include different annual plant parts. While nitrogen was preserved in the seed samples which we tested, the EA-IRMS system used in this study was not sensitive enough to obtain a readable or reliable δ^{15}N value, necessitating future methodological development (i.e. a set-up with additional sensitivity). This was also the case for modern whole fruit and pip samples that we tested which had nitrogen contents of 1–2 % (Table1.). This highlights one major issue in terms of the application of isotopic analyses to perennial crops, relative to cereals, and will require further work in future. A further route of analysis in this regard might be analysis of dried olive and grape fruit remains, as has been found in some contexts in Southwest Asia and North Africa, including grapes from the Egyptian Abydos Tomb U – J, where 47 jars contained both grape pips and whole grapes (Leeman, 2013), as well as grapevine fruit and fruit skins remains from Anatolian Kurban Hoyuk and Tell Tayinat (White and Miller, 2018), and whole grapes from Numeira in Jordan.

Finally, the lack of any previous research on δ^{15}N values for olive and grapevine or, more generally, any perennial fruit plants from Southwest Asia from archaeological contexts makes any produced datasets difficult to interpret at present, and would also require further expansion and investigation beyond the purely analytical issues.

We propose a multi-stage solution plan to resolve the identified problems, as follows:

i. Isotopically examine modern–day uncharred fruits and fruit parts (seeds, fruit flesh, rind) derived from the plots of well-documented, differentiated growing conditions: climate, weather, manuring/watering regime.
ii. Conduct EA-IRMS analysis on multiple, sensitive instruments, preferably designed for low nitrogen-containing samples.
iii. Conduct charring experiments of selected modern remains in order to recognize potential charring offset.
iv. Examine isotopically the species from archaeological contexts (e. g. where there are dried fruit remains) from comparable plant parts (seeds, whole fruit, skin).
v. Study isotopic values of olive and grape remains from archaeological contexts where associated palaeoenvironmental or historical information into crop management exists for comparison.

7. Concluding remarks

Archaeological evidence documents the cultivation of perennial plants such as grapes and olives in the Levant starting during the Chalcolithic era (Langgutt et al. 2022), when the previous economic system, based on the cultivation of annual plants, began to be gradually

[1] In Ehrlich et al. (2022) data collected from around 500 olive pits allowed to define ’wet’ and ’dry’ periods. The Early Bronze Age period (defined in the article as 3900–2500) consists of both wet and dry periods.

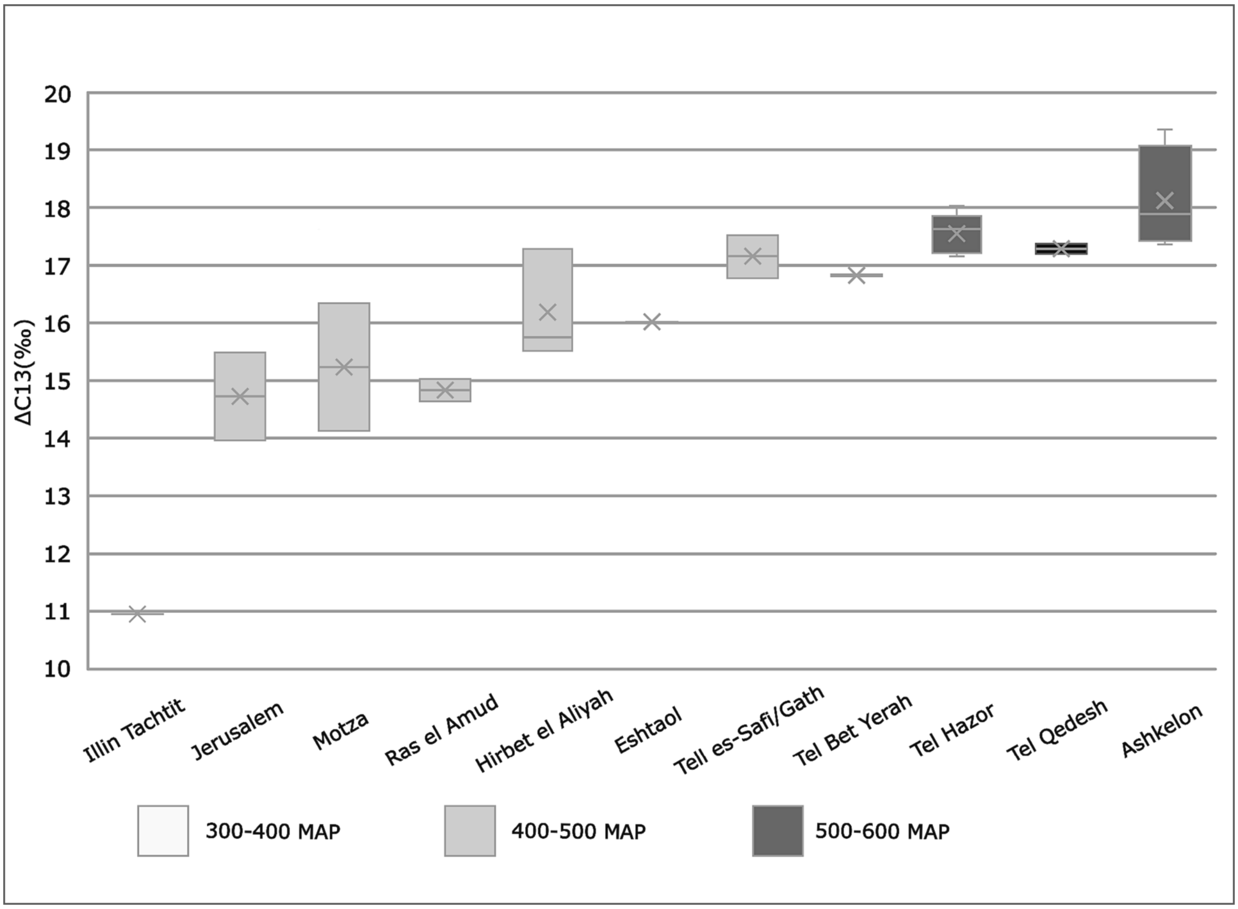

Fig. 2. Shows the results of Δ13Colive pits values for Tel Qedesh plotted with the Δ13C values of Early Bronze Age levantine sites presented in Ehrlich. et al. (2022). Sites are color - coded by modern annual precipitation (MAP). To preserve the continuity of the method presented in Ehrlich et al. (2022) paper, only contexts with radiocarbon dates are included.

Table 1
Presenting the results of different plant parts for percent nitrogen content.

Sample	%N
modern grape fruit flesh	1.02
modern grape whole fruit	1.87
modern grape pips	2.16
modern olive fruit flesh	0.83
modern olive fruit stone	0.85

replaced by an integrated mixed arable farming–husbandry system (Sherratt, 1984; Greenfield, 2010; Hodder, 2011). Cultivation and later commodification of perennials, a major part of the process of social and economic diversification in the Bronze Age, ultimately led to the emergence of cash–crops, which was argued to have been one of the pillars of early urban economies (Sherratt, 1999). As highlighted in this paper, very little research has so far been done to understand the processes which led to increasing management of perennial fruit plants, leaving this topic open for future multidisciplinary research. One potential solution is the application of stable carbon and nitrogen isotope analysis to archaeological remains of these plants to study past growing and cultivation conditions, a methodology that has been proven to be successful in the context of grain and legume crops (Maltas et al., 2022, Nayak et al., 2022, Stroud et al., 2021, Wallace et al., 2013, Bogaard et al., 2013, Bogaard et al. 2007). The experiments conducted on selected perennials in this study have allowed us to identify crucial problems with application of the $\delta^{13}C$ and $\delta^{15}N$ analysis to archaeological olives and grapes. We present a proposed research plan to address some of the major challenges identified in applying this methodology in future studies.

CRediT authorship contribution statement

Karolina Joka: . **Sean Hixon:** . **Mary Lucas:** Formal analysis, Writing – original draft. **Ido Wachtel:** Resources, Finding, Archaeological data. **Uri Davidovich:** Finding, Archaeological data, Editing. **Luis Gonzaga Santesteban:** Editing, Consultancy on modern botanical data. **Patrick Roberts:** Editing, Stable isotopes analysis supervision.

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

Data will be made available on request.

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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.2024.104410.

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Exploring the potential of stable carbon and nitrogen isotope analysis of perennial plants from archaeological sites: A case study of olive pits and grape pips from Early Bronze Age Qedesh in the Galilee: Supplementary Material.

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1. Archaeological samples

The archaeobotanical samples derive from two areas placed in western part of Tel Qedesh archaeological site: an Early Bronze I fortification, named Area C, and chronologically later to Early Bronze II – residential area. The list of the samples chosen for stable analysis research with context descriptions are provided in Table S.1. The selected contexts have been then subsampled for radiocarbon dating analysis, which have been conducted in Poznań Radiocarbon Laboratory – the results are provided in Table S.2.

Site	Area	Locus	Material sampled
Tel Qedesh	B1	L21B1137	2x olive seed, grape seed
Tel Qedesh	B1	L21B1121	4x olive seed, grape seed
Tel Qedesh	B1	L19B1007	2x olive seed
Tel Qedesh	C1	L19C1010	2x olive seed, grape seed
Tel Qedesh	C1	L19C1007	olive seed
Tel Qedesh	B1	L21B1129	olive seed, grape seed
Tel Qedesh	B1	L19B1012	olive seed, grape seed
Tel Qedesh	C1	L19C1008	olive seed
Tel Qedesh	B1	L19B1017	olive seed
Tel Qedesh	B1	L21B21122	olive seed, grape seed
Tel Qedesh	C1	L19C1013	grape seed

Tel Qedesh	B1	L21B1133	2x grape seed
Tel Qedesh	B1	L19B1010	grape seed

Tab. 1 Presenting list of samples with contexts chosen for stable isotopes analysis

Site	Area	Locus	Radiocarbon date chronology
Tel Qedesh	B1	L21B1129	4340 ± 40 BP
Tel Qedesh	B1	L21B1121	4365 ± 35 BP

Tab. 2 Presenting list of radiocarbon dated samples

2. FTIR results

Fourier Transform Infrared Spectroscopy (FTIR) uses incident and reflected infrared light to infer the absorbance spectrum of a given material, which is ultimately sensitive to chemical bonds that are present in molecules of a given mixture. We gathered attenuated total reflectance (ATR) FTIR data from all powdered seeds using a Bruker Vertex 70X benchtop FTIR housed at the laboratories of the Max Planck Institute of Geoanthropology, Germany. Approximately 1-2 mg of bulk seed powder was applied to cover the diamond in each case, the anvil was hand-tightened, and one IR spectrum was collected per sample. Spectra were collected with a resolution of 4 cm^{-1} and 64 scans in the range of 4000-400 cm^{-1}. The diamond was cleaned with Ace between sample measurements, and we evacuated the sample compartment prior to each measurement. Data were acquired with the software OPUS, backgrounds were removed using 10× rubberbanding, and spectra were differenced for the sake of data visualization with various scale factors using Spectragryph.

We found variation among IR spectra according to charring (Fig. 1), antiquity (Fig. 2), and pretreatment (Fig. 3).

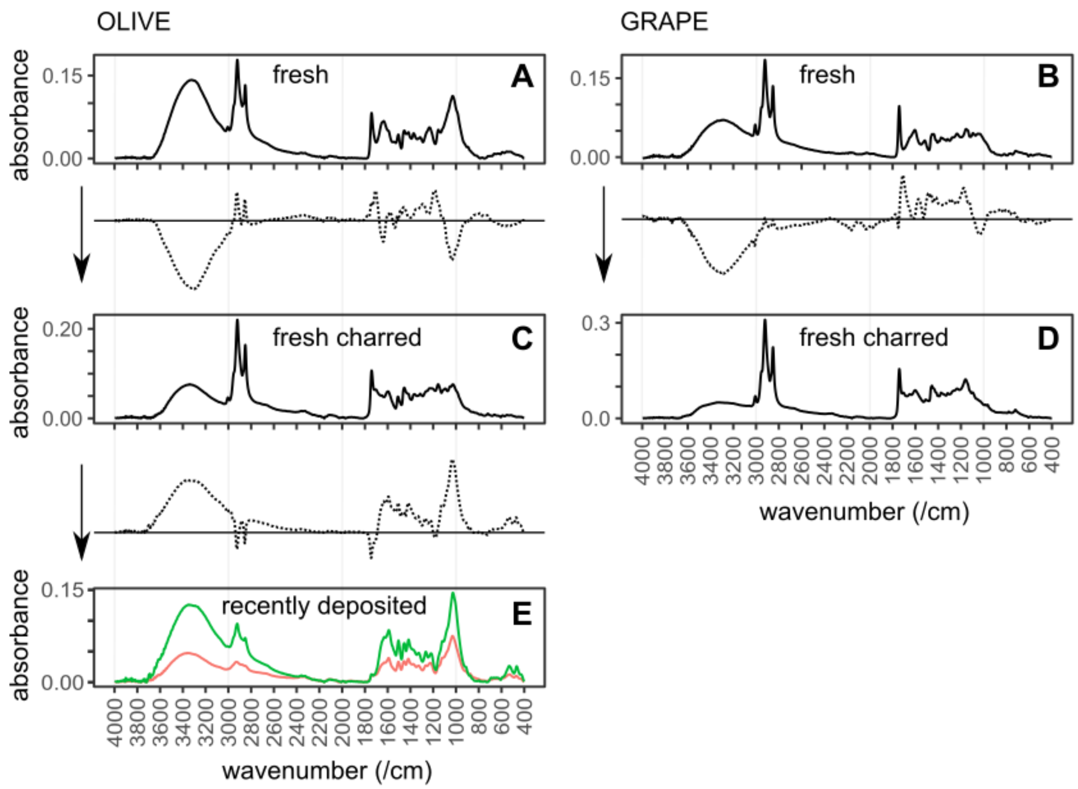

Figure 1. IR spectra from fresh olive pit (A), fresh grape pip (B), fresh charred olive pit (C), fresh charred grape pip (D), and a couple of recently deposited olive pits (E, with specimen 31 in red and 32 in green). Relative differences between IR spectra (with directions indicated by arrows) are shown as dashed lines that vary around a relative difference of 0 (marked with horizontal black lines).

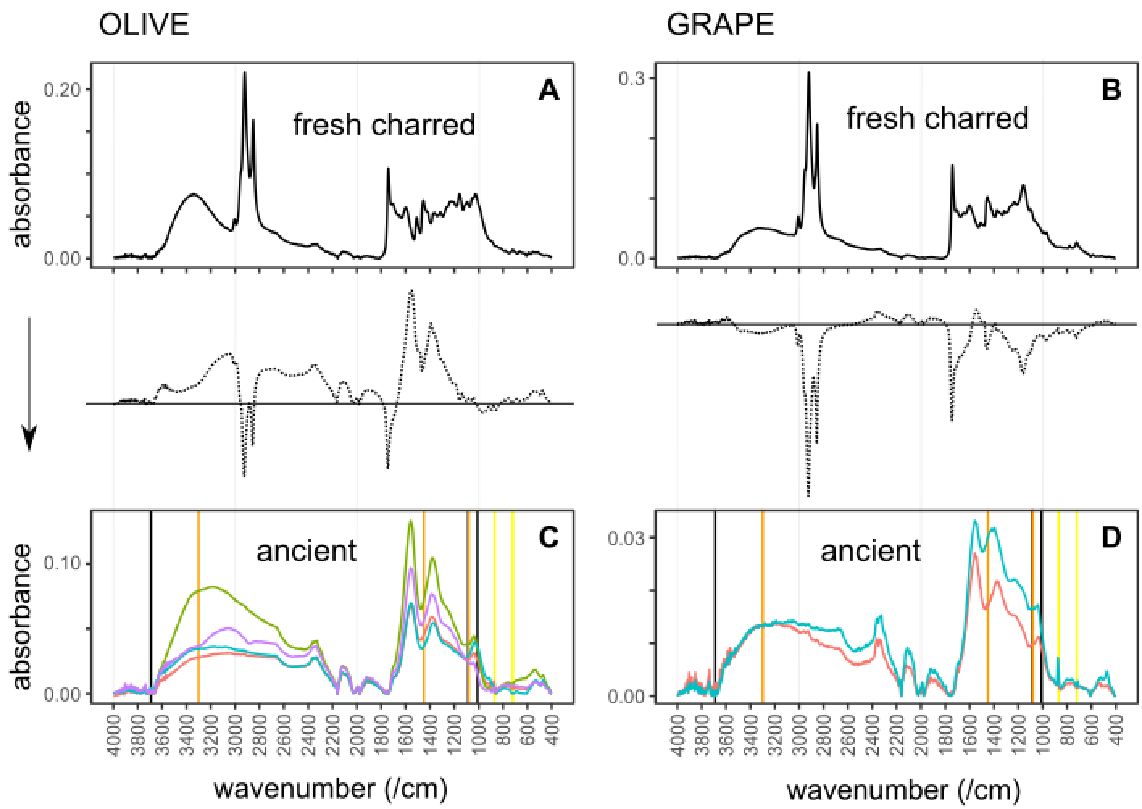

Figure 2. IR spectra from fresh charred olive pit (A) and fresh charred grape pip (B) relative to spectra from ancient olive pits (C) and grape pips (D). Relative differences between IR spectra (with directions indicated by arrows) are shown as dashed lines that vary around a relative difference of 0 (marked with horizontal black lines). Frame C includes data from specimen 13 (red), 18 (green), 23 (blue), and 25 (purple), and frame D includes data specimen 2 (red) and 3 (blue). Vertical lines in C & D indicate absorbance bands noted by Vaiglova et al. (2014) that are commonly associated with exogenous nitrates (orange), carbonates (yellow), and humic acids (black).

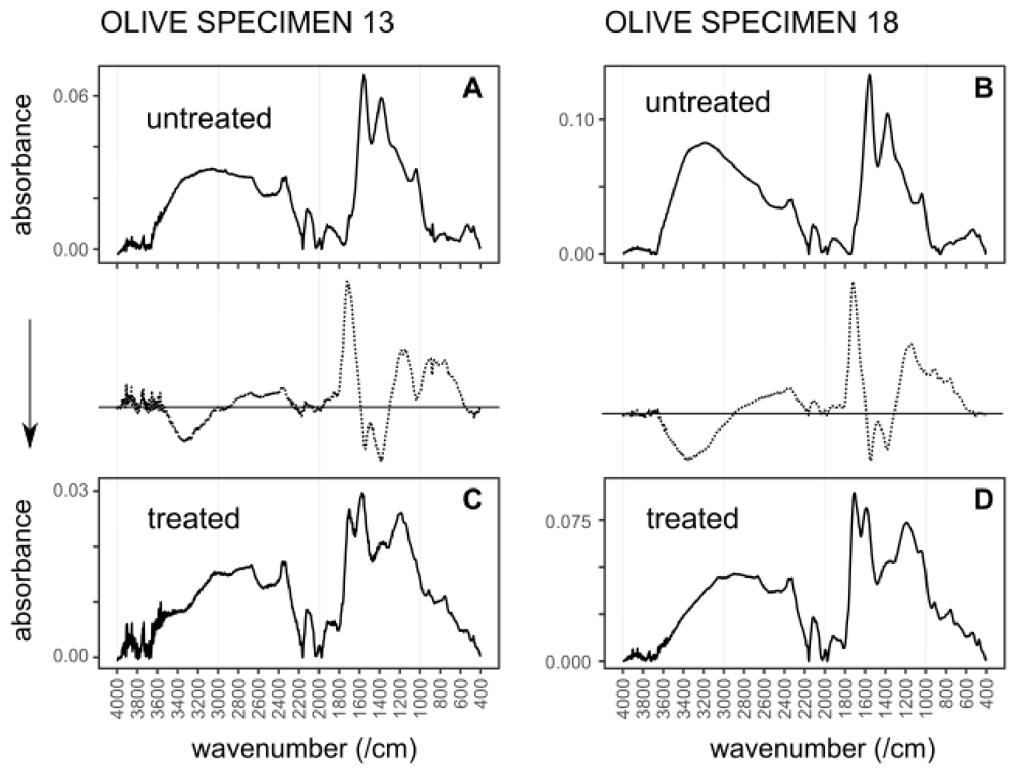

Figure 3. IR spectra from two ancient olive seeds both before treatment (A & B) and after treatment in a weak acid (C & D). Relative differences between IR spectra (with directions indicated by arrows) are shown as dashed lines that vary around a relative difference of 0 (marked with horizontal black lines).

Past research has established that olive pits are composed primarily of fibre (~47% of dry weight), lipids (~30%), and proteins (~17%, Maestri, et al. 2019). Note that, given that protein is ~16 %N, we expect modern olive pits to contain ~2.7 wt. %N. Existing data suggest that fiber and protein are somewhat less abundant in grape pip than in olive pits (Ma and Zhang 2017).

The broad absorbance band associated with O-H stretching (~3600-3000 cm^{-1}), present in fresh olive pit and grape pip spectra (Fig 1A & B), is likely related to water and fibre. The relatively pronounced absorbance associated with the C-H stretching (~2900 cm^{-1}) may be associated with lipids and fibre. Bands following from C=O stretch (particularly ~1770 cm^{-1}) and from C=C stretch at lower wavenumbers are likely associated with fibre, and part of the peak ~1000 cm^{-1} that is particularly broad in the fresh olive spectrum (Fig. 1A) may follow from C-O present in fiber. The absorbance band ~1650 cm^{-1} in both fresh seed spectra likely reflect the presence of amines.

Combustion and pyrolysis during sample charring creates a variety of residues that are well beyond the scope of this article to identify. Generally, changes to olive and grape IR spectra during charring are similar (Fig. 1C & D). In both cases, charring diminishes the band associated with O-H stretch, which likely follows at least partly from the dehydration of the sample. The band associated with the C=O stretching ~1770 cm^{-1} remains prominent following charring, but that associated with amines (~1650 cm^{-1}) and C-O (~1000 cm^{-1}) are diminished in both cases.

The IR spectra from recently deposited olive pits (Fig. 1E) include O-H and C-O bands that make them appear more similar to the fresh olive pits than to the freshly charred olive pits, which suggests that the former were never charred. However, the less prominent C-H band (~2900 cm^{-1}) and diminished C=O band (~1770 cm^{-1}) in the spectra from recently deposited olives reflect some extent of diagenesis.

Despite generally low IR absorbance values from ancient seeds, IR spectra among ancient olive pits and grape pips are qualitatively similar (Fig. 2). As with spectra from the recently deposited olive pits (Fig. 1E), those from ancient olive pits and grape pips (Fig. 2C & D) are missing the C-H band (~2900 cm^{-1}) and C=O band (~1770 cm^{-1}) that are prominent in the spectra from the fresh charred samples (Fig. 2A & B). This suggests that many of the diagenetic changes visible in ancient seed IR spectra occurred soon after deposition.

The absence of absorbance bands in ancient seed IR spectra that are associated with nitrates suggest that nitrates are an unlikely source of contamination. The same is true for carbonates, although one ancient grape pip (specimen 3) includes traces of carbonates at ~870 and 720 cm^{-1}. The absorbance bands that Vaiglova et al. (2014) noted for a humic acid sodium salt from Thermo Scientific (~3690, 1080, and 1010 cm^{-1}) are not clearly present in spectra from our ancient seeds, but there is potential for interference with a band ~1000 cm^{-1} that is present in the fresh charred olive pit (Fig. 2A).

However, the consistently prominent absorbance bands ~1375 and 1555 cm^{-1} in the spectra from ancient seeds reflect a combination of bonds (possibly N-O and S=O) that are not apparent in the spectra from fresh charred samples. These absorbance bands likely reflect the presence of a combination of humic acids other than those studied by Vaiglova et al. (2014). Indeed, although humic acid has the ideal formula $C_{187}H_{186}O_{89}N_9S_1$, the composition of and IR spectra humic acids vary widely according to soil properties (Haworth 1971; Kar, et al. 2011; Niu, et al. 2019).

A fundamental limitation of using IR spectra to detect exogenous humic acids follows from 1) the similar bonds present in plant fiber and humic acids and 2) the fact that humic acid may be endogenous (Ascough, et al. 2011). Consequently, we are unable to conclude that the altered IR spectra from ancient seeds reflects the presence of exogenous humic acids with a distinct stable isotope content. (Note that we are similarly unable to conclude that exogenous humic acids with a distinct stable isotope content are absent based on similarities between ancient and fresh seed IR spectra.)

IR spectra from two ancient olive specimens include consistent changes following acid-only pretreatment (Fig. 3). The reduction in the aforementioned absorbance bands ~1375 and 1555 cm^{-1} reflects the loss or at least alteration of material not present in fresh charred olive pits. Acid treatment is also associated with increased absorbance ~1700 cm^{-1} and 1190 cm^{-1}, which may follow from more prominent C=O bond stretching and C-O bond stretching, respectively. It is difficult to say whether this entails removal of humic acids, endogenous fibre, or both.

3. EA-IRMS stable isotope results

The elemental analyser isotope ratio mass spectrometer (EA-IRMS) simultaneously measures the $\delta^{13}C$ and $\delta^{15}N$ as well as the %C and %N content of bulk organic material. The IRMS system measures these values by measuring the sample carbon and nitrogen against CO_2 and N_2 reference gases of known isotopic value. In order to obtain an accurate measurement of the sample values on the Thermo Delta V Advantage IRMS system used in this study, a minimum sample peak intensity of 1000mV is needed. When this minimum is not reached, the measured delta values cannot be used as they are outside the accuracy range of the mass spectrometer

(Fig. 4).

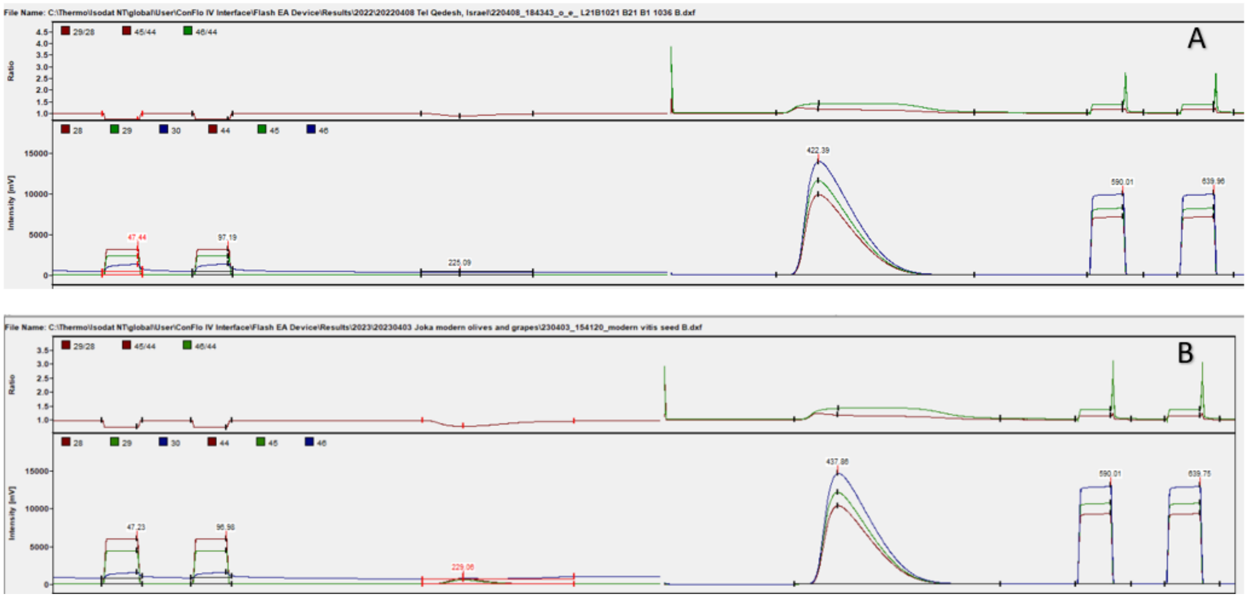

Figure 4. Example chromatograms from this study. The first two peaks are the two N_2 reference gas peaks, followed by the sample nitrogen peak and sample carbon peak, and lastly the two CO_2 reference gas peaks. Chromatogram A is of the archaeological olive pit sample o_e_L21B1021_B21_B1_1036. Chromatogram B is of the modern olive pit sample. Nitrogen samples were run at a 0% dilution with a N_2 reference peak intensity of 5000mV. Carbon samples were run at a 70% dilution with a CO_2 reference peak intenisty of 8000mV. Both chromatograms display a nitrogen peak outside of the accuracy range and a carbon peak inside the accuracy range of the mass spectrometer.

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Plant commodification in Northern Mesopotamia: evidence from the Early Bronze Age site of Kani Shaie, Iraqi Kurdistan

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One of the milestones in the trajectory of economic and social change that spurred increasing societal complexity, and urbanization was the commodification of natural resources, such as plants, animals, and their derived products. In this paper, I examine new evidence of agricultural surplus in a small-scale Early Bronze Age (dated approximately to 2900 to 2300 BCE) community at Kani Shaie in the Bazyan Valley, Iraqi Kurdistan, situating it within the broader context of early commodification and the redistribution of staple foodstuffs. Excavations at an architectural complex dated to the early phase of the EBA suggest its function as a food storage and redistribution center, supported by the presence of administrative remains (sealings), restricted access to the space, and carefully stored agricultural crops, likely intended as the basis for meals. Considering the strategic location of Kani Shaie at a junction between the mountainous Zagros region and the Mesopotamian lowlands, the site's role as a redistribution center can be analyzed within the context of mobility networks linking lowland plains and highland valleys. This contributes to the broader discussion on the role of small, remote administrative centers in the commodification of plant resources, both preceding and existing outside major centers of urbanization.

KEYWORDS

archaeobotany, storage, commodification, Early Bronze Age, Northern Mesopotamia

1 Introduction

Decades of intensive research on past social and settlement developments have demonstrated that the emergence of centrally administered exchange and trade—well-documented in the urban hubs of the Bronze Age in Southwest Asia—was a consequence of profound transformations in the social and economic organization of Neolithic and Chalcolithic communities (e.g. Childe, 1950; Jacobs, 2000). Crop cultivation was a critical factor in these changes. The establishment of cereal-based economies at the end of the Neolithic influenced landscapes (e.g., arable fields, deforestation, soil erosion, and arable soil formation), ecology (e.g., coevolution of domesticated plants and animals, weeds, and commensals), and society itself (Ellis, 2015; Fuller and Stevens, 2017; Zeder, 2017).

The ability to produce food through farming, as opposed to a reliance on hunting and gathering, enabled a sedentary lifestyle that facilitated food storage. This practice protected food from environmental conditions, allowed for the accumulation of foodstuffs over extended periods, and reduced dependence on seasonal availability (Hastorf and Foxhall, 2017). The gradual development of agricultural technologies, such as extensification of labor practices,[1] ultimately led to food surpluses—quantities of food exceeding the immediate survival needs of producer communities. These surpluses allowed for culturally and socially conditioned behaviors such as reciprocity and gift-giving (Hastorf and Foxhall, 2017; Joka et al., 2024a). Stable food supplies supported population growth and enabled the emergence of non-agricultural specializations (e.g. ceramic production, textile production but also various food producers aside of farmers, e.g. bakers) (Wengrow, 2008; Hald and Charles, 2008) and the broader distribution of goods, culminating in the commodification of agricultural crops and food resources (Scott, 2017). This process was instrumental in the development of complex societies and urbanization.

One significant driver of these transformations was the increasing importance of delayed-return cultivation practices, which emphasized the long-term benefits of agricultural investment (e.g. Miller, 2000; Boivin et al., 2016; Morris, 2010).

This study examines new evidence of crop surplus production, storage, and exchange in a small, non-urban community. It contextualizes these findings within the broader processes of early commodification and redistribution of staples and explores the long-term consequences for social complexity. As widely recognized (e.g. Sherratt, 1999; Benati, 2015; Wengrow, 2008; Bevan, 2010; McMahon, 2020), the commodification of plants gained momentum during the Early Bronze Age. However, identifying archaeological indicators of this process remains challenging. Archaeobotanical deposits have typically been studied in the context of settlement economies or diets and, more recently, to understand cultivation techniques such as water management or manuring (e.g. Bogaard et al., 2013; Wallace et al., 2015).

Archaeobotanical data can, however, be analyzed through a multidimensional lens to reflect social changes and the economic adaptations of settlements over time. Evidence from Kani Shaie (Bazyan Valley, Iraqi Kurdistan) suggests that plants were transformed into commodities, stored and redistributed from early redistribution centers. In a broader perspective, this evidence contributes to ongoing debates (Graeber and Wengrow, 2021; McMahon, 2020; Morris, 2010, 2005; Algaze, 2008) regarding the role of small administrative centers in shaping the delayed returns of cultivation practices.

2 Commodification of plants

Hirth (2020) defines the economy as a "socially mediated form of material provisioning and interaction involving the production and allocation of resources among alternative ends." This definition implies that the economy reflects social behaviors related to the material aspects of everyday life. These interactions are shaped by environmental resources and their control by individuals or groups. The entire mechanism is influenced by the dynamically evolving cultural context, where the value of a resource (henceforth also referred to as a product) and the controlling party is often associated with political, religious, or other social activities (Hirth, 2020).

The process of attributing value to such resources—such as agricultural crops processed for storage or exchange, raw materials crafted into artifacts, environmental resources (e.g., water, stone, wood), or real estate (e.g., coastlines, arable fields, buildings)—is called commodification—production of commodities, where the resource is being marked as a commodity, and then exchanged for an equivalent value to a counterpart. Whether an item becomes a commodity depends on social context and can vary between individuals and groups (Kopytoff, 1986). As this process unfolded gradually, understanding the commodification of various goods and resources requires a diachronic perspective. Archaeologists must identify the origins of these processes and define the geographical and cultural circumstances that facilitated them.

Regardless of geographical locales, subsistence items—resources and products essential for survival and safety, such as staple foods and secondary products derived from plants and animals—inevitably became commodities, either locally or through long-distance exchange.[2] A second category of commodities includes prestige goods, which signify the social importance of individuals, groups, or locations and follow different dynamics.[3]

In the paper *Different Types of Egalitarian Societies and the Development of Inequality in Early Mesopotamia* (2007), Marcella Frangipane argues that the commodification of foodstuffs, land, and livestock in Northern Mesopotamia began to emerge during the sixth millennium BCE. This was in the context of a mixed economy that combined agricultural and livestock exploitation. Agricultural development worked alongside transhumance practices, leading to specialized use of landscapes for animal or plant resources. This created complementarity and interdependence within growing populations: one part of the community engaged in sedentary farming while the other practiced seasonal pastoralism. Both groups required access to a full range of products, necessitating an exchange system to ensure subsistence items were available year-round. This dynamic prompted the emergence of storage and redistribution facilities.

Although it is difficult to pinpoint when the commodification of staple crops first occurred, the phenomenon can be traced through changes in material culture, including architecture and artifacts. Evidence from as early as the Neolithic—such as storage facilities at Anatolian Çatalhöyük and Greek Toumba Kremast (Urem-Kotsou, 2017; Bogaard et al., 2009)—indicates that systems of food sharing predated commodification. Collective storage and management of staple goods were key features of seventh-millennium BCE societies in Southwest Asia, as seen in the social organization of Hassuna

1 It is generally agreed that in the area of Northern Mesopotamia the increased crops production was achieved through agricultural extensification: cultivation of larger areas of land, while entailing lower manure inputs per unit area (Styring et al., 2017).

2 For example, cotton and yams in Maya civilization (Chase et al., 2008; Smith, 2011), linen and sandstone in Egypt (Shaw, 2002), and greenstone and spinifex resin in pre-colonial Australia (Pitman and Wallis, 2012; Smith and Burke, 2007) exemplify a global trend of resource commodification.

3 Prestige goods must stand apart from everyday items in material, craftsmanship, function, or all these aspects, moreover, their form and significance are shaped not only by material availability but also by cultural contexts (Frangipane, 2007).

and Umm Dabaghiyah-Tell Sotto cultures in the Jazeera region (Frangipane, 2007).

An advanced redistributive system is exemplified by the "Burnt Village" at Tell Sabi Abyad (Akkermans and Schwartz, 2004), where hundreds of *cretulae* bearing impressions from over 65 different seals were discovered among charred plant remains in large communal storage buildings (Akkermans and Duistermaat, 1996). As Late Neolithic societies, including those in the Northern Mesopotamia, are generally viewed as egalitarian (Frangipane, 2007), the system at Tell Sabi Abyad likely functioned as one of egalitarian redistribution. Goods stored there remained within the community, intended for communal use rather than profit accumulation (Graeber and Wengrow, 2021).

Over the ∼4,000 years between these Late Neolithic egalitarian economies and the emergence of the first cities, both cereals (wheat, barley, pulses) and newer perennial crops (olives, figs, grapes) were transformed from subsistence staples into commodities transported from producers to consumers (Sherratt, 1999, 2011; Fuller and Stevens, 2019). Value was added by accumulating surplus crops and through labor-intensive processing, such as producing oil from olives, wine from grapes, or dried fruit from various plants (Joka et al., 2024b; Fuller and Stevens, 2019; Sherratt, 2011, 1999). These activities were geared toward redistribution, but this time with the aim of profit rather than mere subsistence (Sherratt, 1999).

The trajectory of these expansive changes in the perception of agricultural crops remains poorly understood. However, the commodification of crops had profound consequences, arguably serving as a catalyst for urbanization. These include the development of land ownership rights and the emergence of social elites, both linked to increasing stratification (Fuller and Stevens, 2019). Given the far-reaching implications of this process, recognizing the emergence of crop commodification is crucial for advancing scholarship, extending well beyond the specific case study discussed in this paper.

3 The site of Kani Shaie

Kani Shaie is an archaeological site situated in Iraqi Kurdistan, within the rural Bazyan Valley, positioned between the cities of Kirkuk to the south-west and Sulaymaniyah to the north-east. The settlement covers ∼3 ha and comprises a primary mound about 70 m in diameter at its base, rising roughly 14 m above the valley floor. Extending northwards is a gently sloping "lower town," where evidence of prolonged occupation has also been identified.

Strategically located, Kani Shaie occupies a pivotal position within the landscape. It lies in the western foothills of the Zagros Mountains, offering facilitated access to the Transtigridian plains to the north-west and routes through mountainous terrain leading north and east toward the Urmieh Basin and Iranian Plateau (Figure 1). Within the Bazyan Valley—a north-west to south-east corridor bounded by the Qaradagh and Baranand hills—Kani Shaie commands a central place. The valley is accessed via the Bazyan Pass to the north and the Bassara Pass to the south, receiving an annual rainfall of 500–750 mm. Springs fed by snowmelt and seasonal precipitation create excellent water drainage, supporting pockets of highly fertile land interspersed with the valley's limestone rock formations. Historical accounts by early European travelers describe the Bazyan Valley as abundant with orchards, vineyards cultivating grapes, barley crops, and cotton plantations (Rich, 1836).

In a broader context, Kani Shaie's location facilitated connectivity and exchange, linking the resource-rich zones of highland and lowland Mesopotamia. Material evidence recovered from five seasons of excavation (2013–2023) reflects its strategic position as a nexus for trade and cultural exchange between the mountainous Zagros region and Mesopotamian urban centers during the early phases of state development (Tomé et al., 2016).

Excavations and stratigraphic investigations at Kani Shaie have uncovered over 4 m of Early Bronze Age (EBA) deposits, dating from ∼2900 to 2300 BCE. In recent years, research has focused on an expanded 200 m^2 excavation area (Area A), aiming to provide extensive horizontal exposure of EBA architectural remains and clearer contextual information. This work has revealed a dynamic settlement during the first half of the third millennium BCE, with at least eight phases of occupation.

These dense EBA deposits accumulated rapidly as thin occupational layers built directly atop one another, occasionally interrupted by periods of abandonment, settlement reorganization, and squatter occupations. The upper 2 m of the mound's EBA levels were heavily damaged by intrusive pits associated with medieval campsites and Ottoman-era graves (Ahmad and Renette, 2023). However, the earlier phases of the EBA, better preserved and supported by radiocarbon dating (Ahmad and Renette, 2023), align closely with contemporary Ninevite 5 type-sites dated to the early third millennium BCE in Northern Mesopotamia.

The architectural features of Kani Shaie are consistent with those found at Ninevite 5 sites in the Tigridian/Eski Mosul Dam region (Roaf, 2011; Lawecka, 2019). Examples include Tell Mohammed Arab (Roaf, 1984) and Tell Karrana 3 (Wilhelm and Zaccagnini, 1993), where mudbrick superstructures were constructed atop stone foundations to define small-scale domestic spaces. At Kani Shaie, evidence for grain storage and administrative activities parallels key Ninevite 5 sites, with the discovery of a large building featuring the distinctive "grill plan" design commonly associated with such functions.

Kani Shaie's strategic position and material evidence underscore its importance as a focal point for exchange and administration, bridging highland and lowland zones during the transformative Early Bronze Age.

4 Materials and methods

Excavations of the Early Bronze Age (EBA) levels at Kani Shaie were focused on Area A (Figure 2) atop the main mound. These levels are subdivided into eight occupational phases, distinguished by variations in architectural construction, layout, and material culture, particularly ceramic typology. The EBA remains are relatively poorly preserved, with deposits rarely exceeding 10 cm in thickness. These deposits often cut into earlier levels and are themselves cut by later activity. Chronological positioning[4] is established through material culture changes, and architectural

4 A detailed radiocarbon dating programme is in development to determine lengths of occupation and hiatuses.

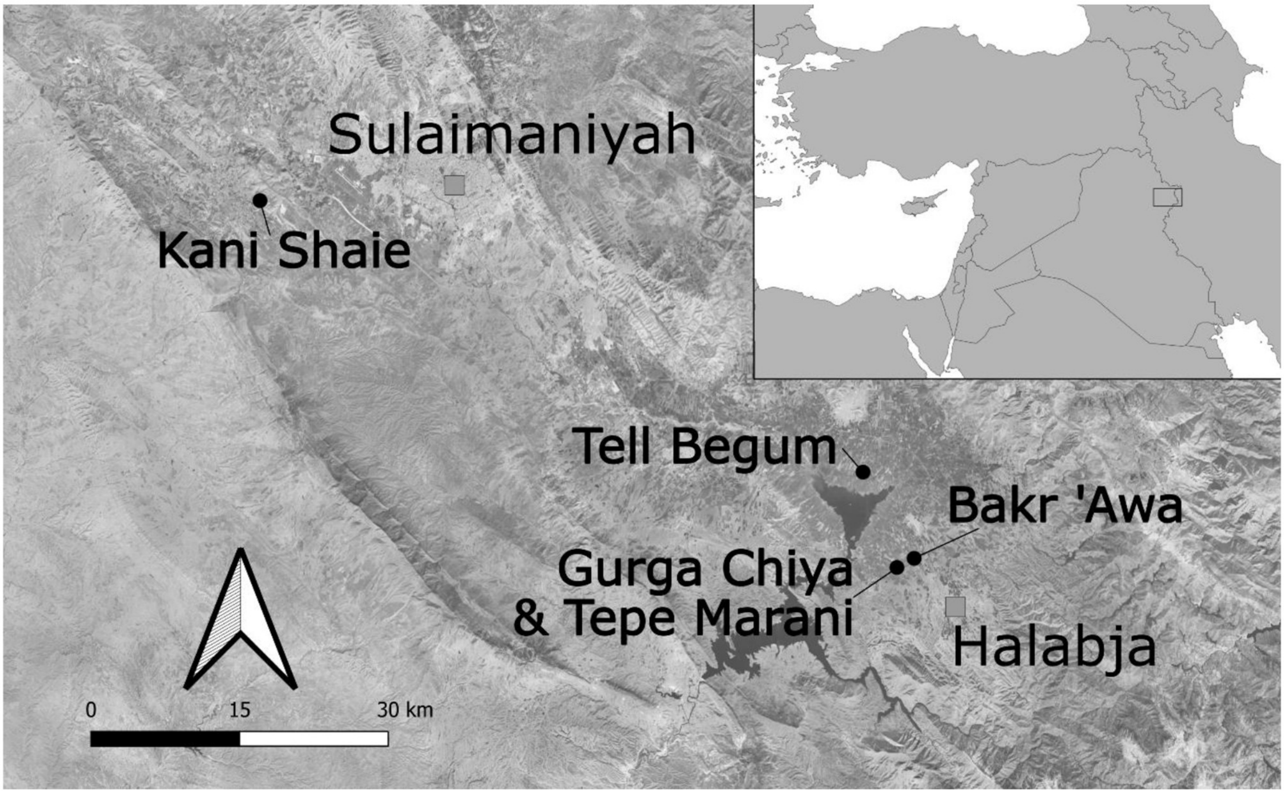

FIGURE 1
Map of the region with the location of Kani Shaie (by J. Hordecki). More detailed map is available in Supplementary Data File.

reconstructions, such as alterations in mudbrick walls. To maintain stratigraphic control, Area A was divided by a central north-south balk, while *ad hoc* sections were retained to examine relationships between contexts. This study focuses on data from a significant context within the area, comprising a grill structure designated as Room A, interpreted as a crop storage facility, and an adjoining rectangular space, Room B, which likely served as a distribution area for stored foodstuffs.

The storage facility (Room A) consisted of a grill structure constructed with reeds and mud plaster atop a foundation of parallel rows of single mudbricks. Similar grill structures have been documented at other EBA sites in Northern Mesopotamia, such as Tell al Raqa'i and Tell 'Atij, (Schwartz, 2015; Paulette, 2015; Mardas, 2019). Artifacts retrieved from the storage area included a large number of pottery sherds—many from medium-sized storage jars—alongside burnt clay sealings and significant quantities of archaeobotanical material, predominantly emmer wheat seeds (Farahani, 2018).

A total of 28 clay sealings were recovered from the collapsed remains of the storage facility. The location of clay sealings close to the entrance of the storage facility and sealings imprints suggests that access to the area was restricted (sealed). Access to Room A was likely controlled through the adjoining Room B, which appears to have functioned as a distribution area for the stored goods. Sealings from the storage room entrance were discarded in a narrow corridor (Corridor 1) (Figure 2) connecting the two spaces. This distribution of sealings may indicate that the storage facility was periodically accessed, with seals broken and discarded each time entry was granted. However to determine the purpose of these sealings more precisely, the spatial analysis must be supplemented with a functional analysis of sealings imprints.

In the adjoining Room B, 34 clay sealings were recovered from the burnt collapse of the space and its immediate vicinity. A cluster of 19 sealings—or 26 when including more dispersed examples—was located in the northern quadrant of the room. This concentration was associated with dense deposits of charred botanical remains and numerous painted pottery vessels, most of which were small cups likely used for individual consumption of food or beverages.

At least 17 of these sealings had been attached to mobile containers such as bags and jars. Nearly all were broken, suggesting that these containers were opened within the room itself. A smaller concentration of charred botanical remains was identified near the southern doorway, alongside a group of three or four sealings and a collection of broken jars with painted decoration.

Preliminary analysis of the sealings, including their functions, material imprints (mainly textile and leather), and seal impression imagery, is ongoing, however clear patterns are emerging. The evidence suggests that foodstuffs, mainly botanical, could be brought into Room B—likely from the northern storage facility (Room A)—possibly for further distribution. The architectural layout and associated artifacts indicate that these spaces were not used for domestic purposes but were instead restricted areas dedicated to the storage and distribution of food.

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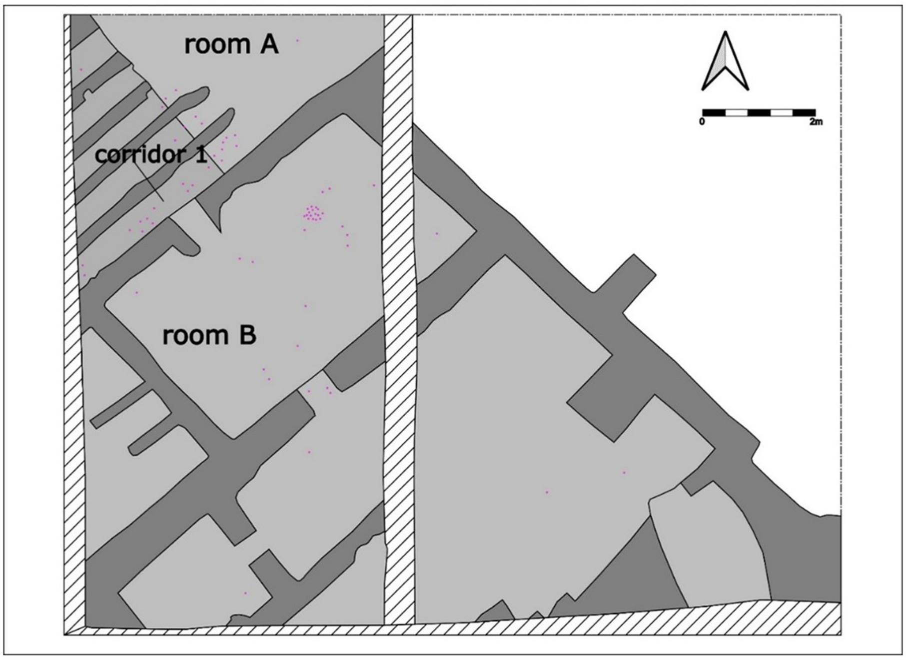

FIGURE 2
A plan of Area A, with the facilities addressed in the text body: room A: grill structure (storage), room B: adjoined rectangular room (redistribution facility), corridor 1: narrow corridor between the rooms. Pink dots: sealings (orthophoto for plan provided Kani Shaie Archaeological Project).

4.1 Environmental sampling strategy

The sampling strategy involved collecting a 2.5-L core soil sample from each excavated context, for contexts with substantial accumulations of archaeobotanical remains, such as those discussed here, a combined method of handpicking and soil sampling was employed. All samples were processed using a flotation machine, with the system adapted to recycle water. Light residues (flots) were collected using a mesh with an aperture of ∼250 µm, while heavy residues were retained in a mesh with a 1 mm aperture. The collected material was air-dried in the shade prior to sorting. Heavy residue samples were manually sorted to recover both organic and inorganic archaeological material. For each light fraction, the total volume (mL) was recorded and then the material was sieved through 2 mm, 1 mm and 500 µm sieves to facilitate the sorting and identification process. The flot volume (ml) and weight (g) were recorded. Macrobotanical remains from the flots were examined using a low-powered binocular microscope (×10–60 magnification). Identification followed standard archaeobotanical procedures, relying on modern seed reference collections housed at the UCL Institute of Archaeology. Differentiation criteria for botanical families, genera, and species were informed by seed atlases (e.g. Anderberg, 1994; Cappers and Bekker, 2006; Cappers et al., 2012), archaeobotanical publications (e.g. Jacomet and Greig, 2006; Jones, 2005; Nesbitt, 2006), open-access online repositories such as the Digital Plant Atlas (https://www.plantatlas.eu/), and personal observations. Plant nomenclature generally adhered to the *Flora of Iraq* (Guest et al., 1966).

The archaeobotanical material analyzed for this research originates from contexts interpreted as part of a foodstuff redistribution area adjacent to the grilled structure,[5] which also featured administrative instruments such as seals. Fourteen samples were collected from this area via flotation, supplemented by hand-picked plant remains recovered during excavation. These samples yielded a total of 1.204 seeds and seed fragments, including wild taxa (the dataset is provided in Supplementary Data File).

5 Results

The samples from rooms A and B at Kani Shaie contained approximately equal proportions of identifiable seeds and indeterminate/fragmentary material, with a ratio of 49% to 51%. In total, five cultivated species—barley, emmer wheat, lentil, chickpea, and pea—were identified, alongside one edible arable weed (Galium sp.; Table 1). The assemblage demonstrates high homogeneity, dominated by staple crops, with barley (*Hordeum vulgare sensu lato*) being the most frequently identified taxon. Indeterminate cereal fragments were the most ubiquitous finds, while crop-processing waste, such as chaff, was almost entirely absent except for a single wheat glume base (*Triticum cf. dicoccum*). Arable weeds were also notably rare.

The archaeobotanical data reflect a regional pattern of agricultural production centered on domestic crops, particularly

5 Archaeobotanical material from grill storage structure reported in detail by Alan Farahani (Farahani in prep.) also has been presented in the ICAANE conference (Farahani, 2018). The archaeobotanical material from this storage structure was not a subject to archaeobotanical analysis conducted for the purpose of this paper, as it will be published as a separate volume.

TABLE 1 Summary of the frequency and abundance of major plant categories across the analyzed assemblage.

Presence	Ubiquity	Sum*
Barley	15.3	180
Emmer	0.9	11
Cereal indeterminate	47.5	560
*Total cereal**	63.6	751
Chickpea	4.9	58
Pea	4.0	47
Lentil	12.9	152
Legumes indeterminate	14.6	172
*Total legumes**	36.4	429

*Including indeterminate categories.

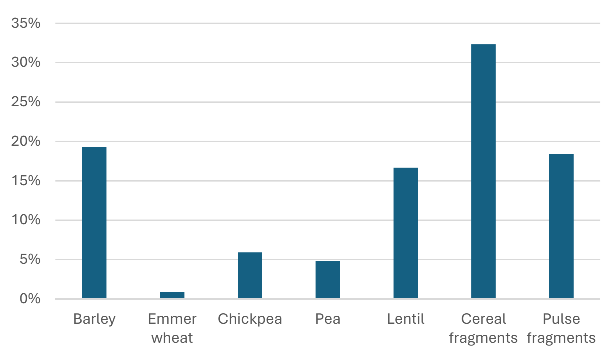

FIGURE 3
Presence of food crops recorded on site by type.

barley (*Hordeum vulgare sensu lato*), emmer wheat (*Triticum dicoccum*), and legumes such as lentils (*Lens culinaris*), peas (*Pisum sativum*), and chickpeas (*Cicer arietinum*) (Figures 3, 4). This pattern is consistent with findings from contemporaneous sites in Iraqi Kurdistan and more broadly across Southwest Asia (e.g., Late Chalcolithic Gurga Chiya and Tel Sureza; Early Bronze Age Tell Brak, Chagar Bazar, and Tell Mozan) (Proctor et al., 2022; Carter and Wengrow, 2020; Diffey et al., 2024; Riehl, 2010). The absence of fruits, nuts, and other edible plants suggests the storage facility was intended to house specific staple crops. Notably, archaeobotanical evidence indicates a division of function between the grill-structured storage (containing predominantly emmer wheat) and the adjoining redistribution facility (dominated by barley, with minimal emmer wheat). This distinction could reflect seasonality in the harvest, or—as commonly suggested—because barley was a major crop grown in Northern Mesopotamia from the fourth millennium onwards[6] (Charles et al., 2010; Schwartz, 2015). The minimal presence of chaff (e.g., barley rachis) and arable weed seeds suggests that threshing and winnowing were conducted off-site, prior to storage. This points to a systematic cleaning process for plant materials before they were stored, distributed, or prepared for consumption (Stevens, 2003). Pulses, which are processed similarly to free-threshing cereals, would have been de-shelled prior to storage (Fuller and Harvey, 2006; Jones, 1987).

The high proportions of fragmentary legumes and cereals appear to result from post-depositional processes, including burning during the collapse of the rooms, rather than evidence of food preparation or crop processing activities conducted on-site.

6 Discussion

The focus on agricultural production and surplus storage identified at the North Mesopotamian Kani Shaie settlement correspond with similar developments reported from the Ninevite 5/Early Bronze Age rural settlements (e.g. Telul eth-Thalathat, Tell Arbid, Tell al-Raqā'I) (Mardas, 2019; Schwartz, 2015; Fukai et al., 1974; Smogorzewska, 2014). The presence of a variety and size[7] of the buildings, such as grill – structured granary racks and *siloi* to store the crops (Tell Karrana 3, Tell al-Raqa'i, Telule el Thalathat) (Mardas, 2019; Schwartz, 2015), in addition to facilities for crop processing, storage and food preparation (e.g rooms with ovens and storage jars, also with the post-processing botanical and food waste; Tell Arbid, Tell Hamoukar, Tell Brak) (Szelag, 2009; Smogorzewska, 2014; Hald and Charles, 2008) seems to confirm that by the beginning of the third millennium BCE the turn toward larger scale storage and post-harvesting processing before storage of agricultural crops already took off in the Northern Mesopotamia. The storage was organized on a large-scale, at a super-household level, and implies that crop-processing was carried out after harvest and before storage. This implies the presence and pertinence of the centralization processes.

Similar practices in other regions of Northern Mesopotamia, including earlier examples from Tell Sabi Abyad, highlight the emergence of administrative systems prior to urbanization (Akkermans and Schwartz, 2004; Wengrow, 2008), however the sealed storage spaces and restricted access at Kani Shaie reflect early centralization efforts, likely intended to regulate surplus and ensure redistribution.

The archaeological and botanical data from Kani Shaie offer valuable insight into the commodification of crops. Commodification, as conceptualized by Kopytoff (1986), involves the transformation of goods into items of value, marked physically or metaphorically as distinct from ordinary goods. At Kani Shaie, the restricted-access granary, sealed storage units, and careful portioning of crops may be interpreted in a category of commodification, suggesting ongoing early commodification processes. These practices added value to the stored crops, both as physical commodities and as part of a redistribution system. However, while these features align with commodification, there is no direct evidence of trade or market-based transactions akin to those seen in urbanized regions

6 The widespread cultivation of barley is likely attributed to its lower demands for water and soil quality. Being more drought- and salinity-tolerant than wheat, barley can achieve high yields even in regions with significant variability in annual rainfall (Charles et al., 2010; Schwartz, 2015, p. 564) which is also recently confirmed by the results of isotopic studies (e.g. Fraser et al., 2011).

7 The size of the buildings and the amount of grain found indicate that supplies kept exceeding the needs of one household in most of the cases.

FIGURE 4
Most ubiquitous plant species recovered from Kani Shaie **(A)**. Barley **(B)**. Lentil **(C)**. Chickpea, scale bar: 1 mm.

of Mesopotamia. Instead, Kani Shaie appears to demonstrate a form of centralized redistribution, where agricultural surplus was collected, stored, and distributed within the community or possibly to external groups.

The geographical position of Kani Shaie, situated between the Zagros Mountains and Mesopotamian lowlands, underscores its potential role as a node in regional exchange networks. Evidence from as early as the fifth millennium BCE suggests the site served as a central hub in the Bazyan Valley, possibly functioning as a stopover for travelers or nomadic pastoralists traversing the highlands and lowlands (Tomé et al., 2016). This strategic location likely facilitated its role in supporting mobile groups and managing surplus crops for broader distribution.[8] The increasing scale of agricultural production at Kani Shaie supports hypotheses that centralized distribution systems developed in response to surplus accumulation. The presence of seals, sealings, and restricted-access storage suggests efforts to manage and track inputs and outputs, possibly as part of a redistribution system. This system may have supported not only the local community but also mobile or specialized groups, such as craftsmen or traders, highlighting the diverse roles played by rural settlements in broader economic networks (Schwartz, 2015; Frangipane, 2007). Similar hypothesis was proposed for rural site of Tell Raqa'i indicating that agricultural surplus produced was perhaps not only consumed locally, but this rural site was integrated into an agricultural network dedicated to grain production for

8 Zagros is a region where the nomadic pastoralism activities, predominantly based on animal husbandry, took place since the Neolithic times (Abdi, 2003). One potential theory is that the produced grain has been collected and designated to feed people and animals involved in a mobile lifestyle focused on pastoralism, in exchange for animal-derived products (Schwartz, 2015).

supplying urban centers, or nomadic societies (Schwartz, 2015, p. 564; 573).

Kani Shaie demonstrates that processes such as centralization and commodification were not confined to urban centers. The evidence for surplus management, redistribution, and administrative systems at this small rural settlement challenges traditional views that associate these features exclusively with urbanization (Graeber and Wengrow, 2021). The presented site then highlights the diversity of pathways to social complexity in Early Bronze Age Mesopotamia. The findings from Kani Shaie contribute to a growing understanding of how agricultural production and resource management laid the groundwork for social complexity. Through better understanding how these processes took place across a range of sites and site sizes, we will be better placed to understand the origins of urbanization and the emergence of various elements often associated with social complexity.

7 Concluding remarks

The Early Bronze Age rural site of Kani Shaie offers critical insights into processes typically associated with urban contexts, such as resource management, centralization, and plant commodification. Evidence from the site, including sealed storage facilities and carefully portioned crops, indicates early forms of surplus management and redistribution. These findings suggest that plant commodification was a gradual process, beginning in rural settlements and laying the foundation for broader economic systems.

Further research in the Bazyan Valley and other parts of Northern Mesopotamia is needed to fully understand the scale and implications of these processes. Investigating rural sites from both the Early Bronze Age and earlier periods will help clarify how agricultural production and crop commodification contributed to the emergence of social complexity. At Kani Shaie, the transition to centralized storage and redistribution highlights the interplay between local agricultural practices and broader economic and social transformations, providing a valuable case study for understanding the roots of urbanization in Mesopotamia.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

KJ: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Gen AI was used in the creation of this manuscript.

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fearc.2024.1529459/full#supplementary-material

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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, Zohary, and Hopf 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 2008), as well as the storage of crop surplus in dedicated areas associated with large and increasingly 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

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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 Late ʻUbaid 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 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

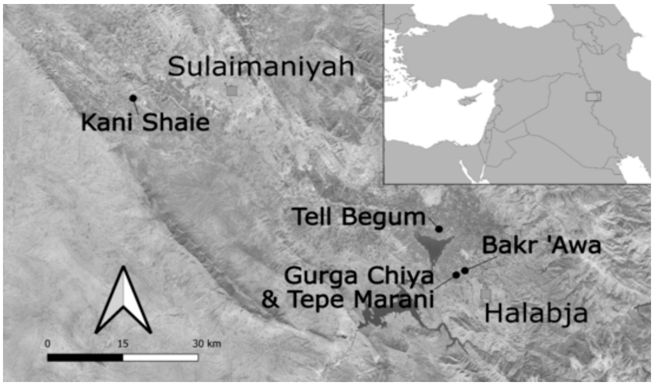

Fig. 1. Map with the location of Gurga Chiya and its vicinity. Created by J. Hordecki.

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 et al 2019; 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 generally followed 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

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

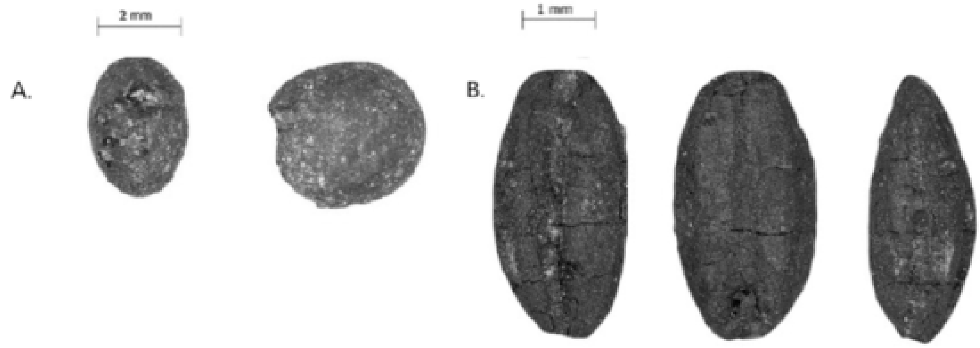

Fig. 3. Dominant archaeobotanical crop remains from storage contexts of Gurga Chiya; A) Lentil B) Barley.

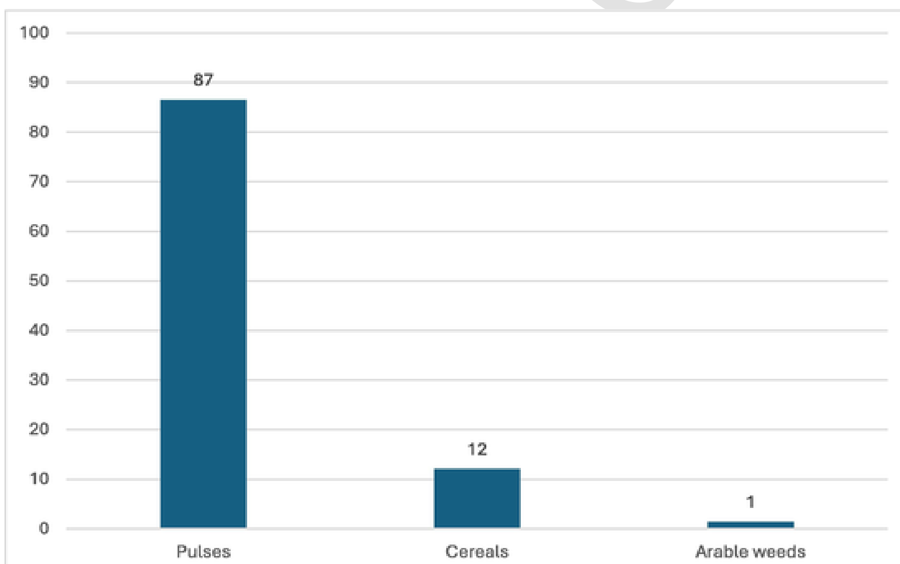

Fig. 4. Macrobotanical assemblage from the discussed contexts, categorized into three general categories.

proximity to the Gurga Chiya site and its comparable data set (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:

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

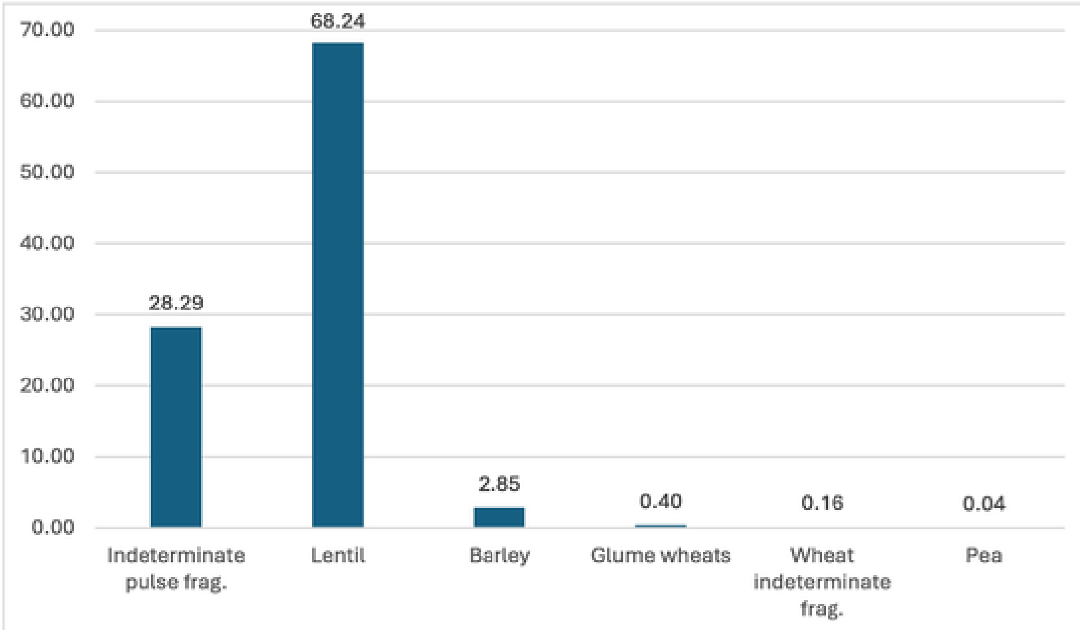

Fig. 5. Breakdown of cultivated food crops.

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 slight domination 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 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.'s (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.

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 $\Delta^{13}C$ 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 $\delta^{15}N$ 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 $\Delta^{13}C$ values suggest that barley was cultivated in slightly drier conditions than wheat, yet further comparison with $\Delta^{13}C$ 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 $\Delta^{13}C$ 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 fertil-

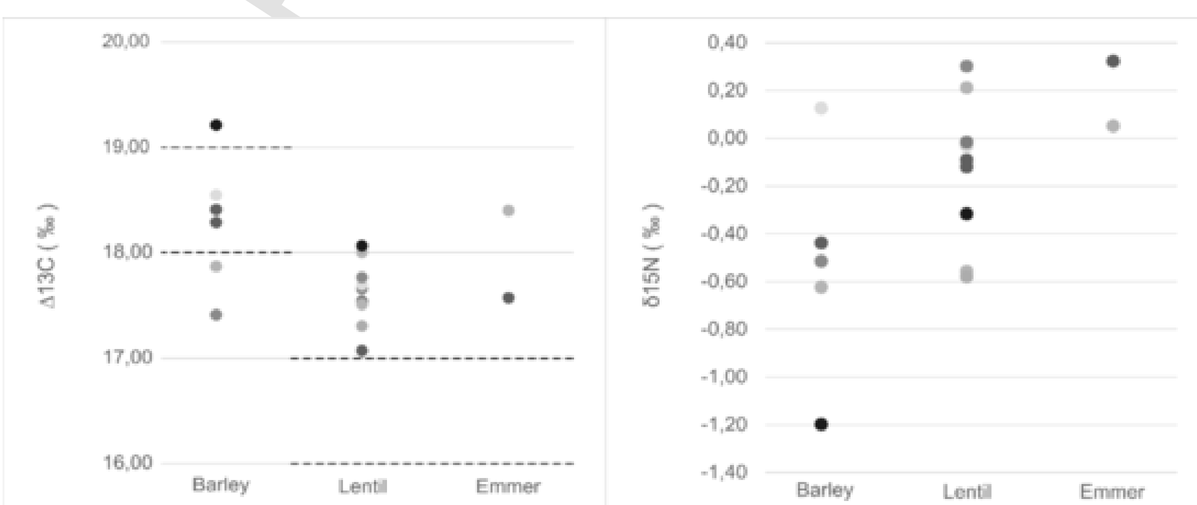

Fig. 6. Presents $\delta^{15}N$ and $\Delta^{13}C$ values of archaeobotanical grains from Gurga Chiya. Dashed lines indicating bands between crops grown under poor (low values), moderate and high (high values) water availability ($\Delta^{13}C$) based on analysis of modern crops presented in Wallace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

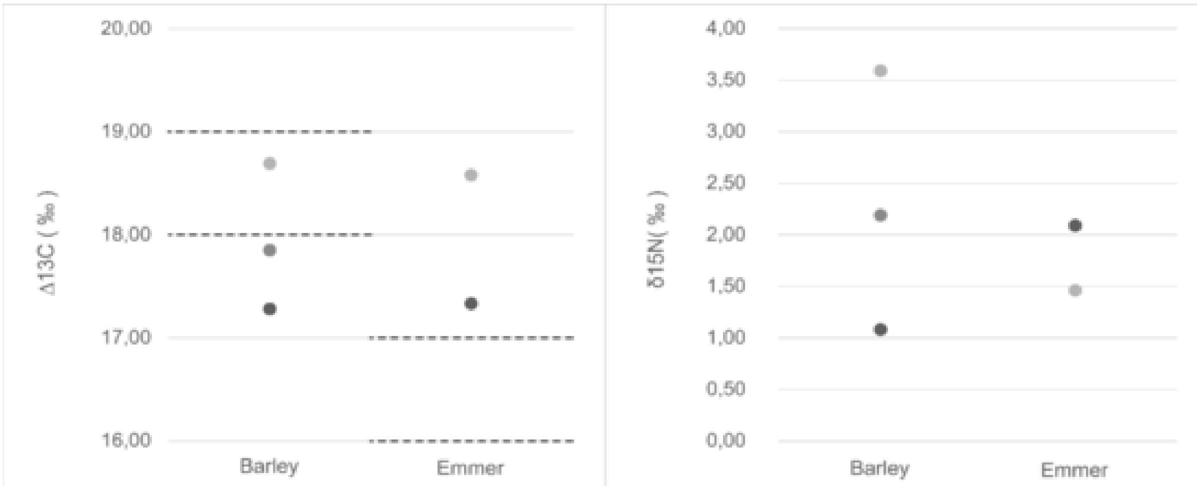

Fig. 7. Presents $\delta^{15}N$ and $\Delta^{13}C$ values of archaeobotanical grains from Tepe Marani. Dashed lines indicating bands between crops grown under poor (low values), moderate and high (high values) water availability ($\Delta^{13}C$) based on analysis of modern crops presented in Wallace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

ized 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 $\delta^{15}N$ 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 conclusions regarding 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 ʻUbaid 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 ʻUbaid, 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 ʻUbaid 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 ʻUbaid 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 ʻUbaid 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.

Uncited references

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CRediT authorship contribution statement

Karolina Joka: Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Investigation, Conceptualization. **Lara González Carretero:** Formal analysis. **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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Data availability

Data will be made available on request.

Appendix A. Supplementary material

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

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Supplementary material for *Storage story: investigating food surplus and agricultural methods in Late Ubaid Gurga Chiya (Iraqi Kurdistan)*.

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1. Radiocarbon dates of context relevant to the paper

Radiocarbon analysis was performed on five burnt lentils from two contexts Context 334 (the main cluster of burnt lentils in Room 1) and Context 328 (the layer above it). Additionally, radiocarbon evaluation was conducted on a sample from a higher Level 1 (LC4) layer, specifically Context 1532 (Fig. 3). The sample from Context 1532 is believed to have originated from the burnt lentil store, along with numerous other burnt lentils found scattered within the LC4 levels, likely redistributed by later disturbances. Radiocarbon dating confirmed this hypothesis (Carter and Wengrow 2020)

After calibration, the Sum Probability indicates a date range of 4530–4340 BCE. with a 95.4% probability (Fig. 13, left). Assuming the lentils belonged to the same crop and were of identical age, OxCal's Combine function yields a narrower date range of 4460–4370 BCE at 95.4% probability (Fig. 13, right).

BETA No.	*Submitter No.*	*Conventional Age*	*2 SIGMA Calibration*	*Stable Isotopes & CN*		*QA Report*
432618	GC-1532_LC	5620 +/- 30 BP	Cal BC 4500 - 4365	δ13C (‰)	-22.8	36781
432617	GC-334_LC2	5570 +/- 30 BP	Cal BC 4455 - 4345	δ13C (‰)	-24	36781
432616	GC-334_LC1	5570 +/- 30 BP	Cal BC 4455 - 4345	δ13C (‰)	-24.7	36781
432615	GC-328_LC3	5630 +/- 30 BP	Cal BC 4520 - 4440 and Cal BC 4425 - 4370	δ13C (‰)	-23	36781
432614	GC-328_LC2	5540 +/- 30 BP	Cal BC 4450 - 4340	δ13C (‰)	-23.7	36781
432613	GC-328_LC1	5660 +/- 30 BP	Cal BC 4545 - 4450	δ13C (‰)	-23.9	36781

Fig. 3 Radiocarbon dates from Gurga Chiya. All samples are AMS-Standard delivery, charred material, pre-treated with Acid/Alkali/Acid (after Carter and Wengrow 2020)

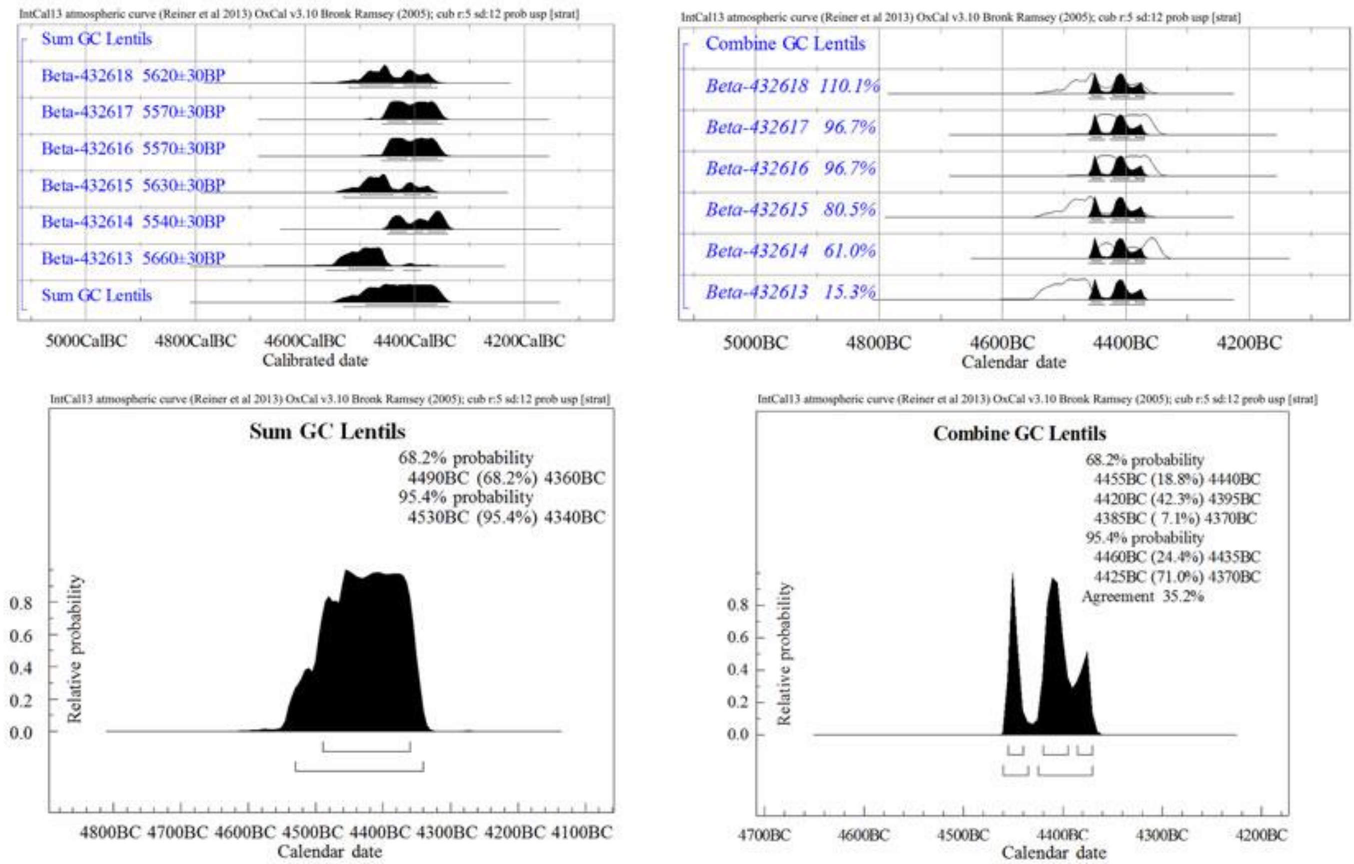

Fig. 4. Calibration of Radiocarbon Dates from Gurga Chiya storage contexts. Left top and bottom: Individual and Sum Probabilities. Right top and bottom: Combined Probabilities (after Carter and Wengrow 2020)

Dane uzupełniające pracy doktorskiej

Zbiór danych będący rezultatem badań archeobotanicznych wykonanych w ramach przedstawionej pracy doktorskiej

A data set resulting from archaeobotanical research conducted as part of the doctoral thesis presented

Cereals	**Plant part**	**No. of species**
Hordeum vulgare	grain	12
Hordeum vulgare hulled	grain	831
	fragment	335
Hordeum vulgare hull-less	grain	1
Triticum sp.	grain	50
	glume base	5
Triticum cf. *monococcum*	grain	10
Triticum monococcum	glume base	9
Triticum dicoccum	grain	126
	glume base	6
Panicum miliaceum	grain	1
Secale cereale	grain	1
cereal indeterminate	presence	5256
Pulses		
Lathyrus sativus	grain	4
	fragment	8
Lens culinaris	grain	9825
	fragment	10 008
Pisum cf. *Sativum*	grain	9
Vicia cf.*faba*	fragment	1
Vicia ervilia	grain	21
	fragment	10
Vicia cf. *sativa*	grain	2
Vicia sp.	fragment	2
legume indeterminate large	presence	8010
Other food plants		
Linum ussitatissimum	grain	g
Cucumis melo	grain	2
Brassicaeae sp.	grain	8
Weeds		
Adonis sp.	grain	1
Bromus sp.	grain	15
Carex sp.	grain	2
Centaurea sp.	grain	3
cf. *Eremopyron*	grain	1
cf. *Fumaria*	grain	1
Galium cf. *tricornutum*	grain	15
Liliaceae sp.	grain	1
Hordeum cf. *Spontaneum*	grain	80
Descurainia cf. *sophia*	grain	56
Phragmites sp.	grain	41
Vaccaria pyramidata	grain	99
Rubus sp.	grain	75
Poaceae sp.	grain	82
weeds indeterminate	presence	10
Other		
food	presence	82

	Total no. of species	**25113**
	Total no of. samples	**56**

Tab. 1. Presenting an overview of all the macrobotanical species recorded at the Gurga Chiya archaeological site during the process of conducting a doctoral dissertation.

Cereals	**Plant part**	**No. of species**
Hordeum vulgare	grain	891
Hordeum cf.*vulgare*	grain	369
Triticum dicoccum	grain	5
Triticum cf. *dicoccum*	grain	14
	glume base	27
Triticum mononoccum	grain	3
Triticum sp.	grain	6
cereal fragments indeterminate	presence	4604
Pulses		
Cicer arietinum	seed	44
	fragment	26
Cicer cf.*arietinum*	fragment	3
Lens culinaris	seed	1856
	fragment	1958
Lens cf. culinaris	fragment	10
Pisum sativum	seed	27
	fragment	1
Pisum cf. *sativum*	fragment	1
legume indeterminate large	fragment	24
Weeds		
Bromus cf.	grain	1
Galium sp.	grain	22
Lens orientalis	grain	1
Malvaceae sp.	grain	3
Poaceae sp.	grain	3
legume indeterminate small	grain	2
weed indeterminate	presence	81
Other		
food	presence	465
	Total no. of species	**10477**
	Total no of. samples	**235**

Tab. 2. Presenting an overview of all the macrobotanical species recorded at the Kani Shaie archaeological site during the process of conducting a doctoral dissertation.

Cereals	**Plant part**	**No. of species**
Hordeum vulgare	grain	4
Hordeum vulgare hulled	grain	1
Hordeum cf.*vulgare*	grain	17
Triticum dicoccum	grain	3
	glume base	15
Triticum cf. *dicoccum*	glume base	1
Triticum mononoccum	grain	5
	glume base	21
Triticum cf. *mononoccum*	grain	1
	glume base	9
Triticum cf. *timopheevii*	grain	4
Triticum sp.	fragment	6
	glume base	43
cereal fragments indeterminate	presence	145
Pulses		
Lens culinaris	seed	28
	fragment	30
Pisum sativum	seed	14
	fragment	2
Vicia ervilia	seed	3
Vicia cf. *Sativa*	Seed	3
legume indeterminate large	fragment	25
Weeds		
Avena cf. *strigosa*	grain	3
Bolboshoneus glaucus	grain	9
Chenopodium sp.	grain	1
Galium sp.	grain	2
Lolium perenne	grain	5
Lolium remotum	grain	15
Lens orientalis	grain	2
Malvaceae sp.	grain	2
Neslia paniculata	grain	1
Poaceae sp.	grain	31
Thymalaea passerina	grain	12
legume indeterminate small	grain	17
weed indeterminate	presence	514
Other food plants		

Malus sylvestris ssp. *orientalis*	grain	5
Olea europea	grain	14
	fragment	140
Pistacia atlantica/palestina	grain	3
Ziziphus spinachristi	fragment	2
Vitis vinifera	grain	25
	fragment	38
nutshell indeterminate	presence	18
	Total no. of species	**1239**
	Total no of. samples	**179**

Tab. 3. Presenting an overview of all the macrobotanical species recorded at the Tel Qedesh archaeological site during the process of conducting a doctoral dissertation.