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Expanding the plain: Using archaeobotany to examine adaptation to the 5.2 kya climate change event during the Anatolian Late Chalcolithic at Çadır Höyük

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ABSTRACT

This study examines how the population at Çadır Höyük on the north central Anatolian plateau modified agricultural and fuel use practices in response to rapid social and environmental change between 3600 and 2900 BCE (Late Chalcolithic and Transitional to Early Bronze periods). Using descriptive and multivariate statistics to explore data from 60 archaeobotanical samples spanning three periods of occupation (3600–3200 BCE, 3300–3100 BCE, and 3100–2900 BCE) the results reveal that the inhabitants of Çadır relied heavily on barley, emmer, lentils, and flax throughout the Late Chalcolithic. Both dung and wood were used as fuel, although dung fuel appears to have been preferentially used. The most significant change throughout this period was a shift from foddering animals to grazing animals on the steppe. This shift corresponded with the 5.2 kya event, a period of increased aridity at the very end of the 4th millennium BCE. By diversifying their agricultural strategies to more risk adverse practices, the population at Çadır demonstrated their ability to be resilient in the face of climate change.

1. Introduction

Çadır Höyük, a mounded site in north central Turkey (Fig. 1), is an ideal location for the study of subsistence practices, fuel use, and local adaptations to climatic change during the end of the Late Chalcolithic (LC) period, 3500–2900 BCE, owing to the fine temporal resolution of 3 distinct building phases at the site, each of which lasted between 100 and 300 years (Table 1). Domestic architecture and courtyards spanning roughly 460 m^2 have been exposed and, combined with metallurgical evidence, indicate that Çadır was developing as a regional rural center at this time. The Late Chalcolithic was a particularly dynamic period at Çadır, experiencing both the ripple effects of the collapse of the Uruk cultural and trading sphere (Steadman et al., 2019b) and a rapid climate shift, often referred to as the 5.2 kya event that occured around 3200 BCE. This climate shift resulted in 300 to 500 years of increased warmth and aridity in SW Asia and is well documented within multiple regional and supra-regional paleoclimate studies (Bar-Matthews and Ayalon, 2011; Cheng et al., 2015; Eastwood et al., 2007; Fontugne et al., 1999; Kuzucuoğlu et al., 2011; Parker et al., 2006; Roland et al., 2015; Turner et al., 2008; Wick et al., 2003).

Çadır Höyük lies within a valley plain at the confluence of two rivers, the Kanak Su which ran NW–SE and the Eğri Su which ran W–E and is now inundated by the Gellingüllü Dam. The top of the mound sits 32 m above the plain that lies at an elevation between 1000 m and 1100 m (Steadman et al., 2007). Excavation began in 1994 and has continued almost annually since then revealing a near continuous sequence dating approximately from 5200 BCE to 1300 CE (Cassis et al., 2019; Ross et al., 2019; Steadman et al., 2019a, 2007, 2008). Excavations at Çadır Höyük have exposed an almost continuous sequence of occupation from the Late Neolithic to the Byzantine with major occupation phases dating to the Late Chalcolithic, the Bronze Age, the Iron Age, and Late Roman and Byzantine (Cassis et al., 2019; Ross et al., 2019; Steadman et al., 2019a). During the LC, Çadır is thought to have been a rural regional center (Steadman et al., 2007, 2008). The archaeological sequence from Çadır Höyük has provided a wealth of knowledge on the settlement history of the north central Anatolian plateau and serves as the longest occupied site with comprehensive archaeological documentation in the region.

Zohary (1973:124) classifies the surrounding environment as Xero-

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Euxinian which is characterized by Euxinian trees and Irano-Turanian steppe groundcover and undergrowth known as "steppe forest." In this environment, grasses like *Stipa lagascae*, *Stipa fontaesii*, *Bromus tomentellus*, *Bromus commutatus*, *Bromus cappadocicus*, and *Poa bulbosa* (Zohary, 1973:180) grow in communities around trees like *Quercus pudescens* and *Quercus cerris* (oaks), *Pinus nigra* (pine), *Sorbus aria* (rowan), *Prunus spinosa* (sloe), *Crataegus laciniata* and *Crataegus monogyma* (hawthorns), *Pyrus elaeagrifolia* and *Pyrus syriaca* (pears), *Celtis tournefortii* (hackberry), *Ulmus campestris* (elm), and *Juniperus oxycedrus* and *Juniperus excelsa* (juniper) (Zohary, 1973).

In this paper, we explore the range of choices and strategies farmers and herders at Çadır Höyük used to respond to the 5.2 kya event. A shift to extensive grazing enabled the population to continue to practice agriculture in broadly the same fashion during a period of increased aridity. Despite the overall climate conditions during the Late Chalcolithic, inhabitants of Çadır Höyük continued to grow a stable roster of crops: barley and hulled wheat were the dominant cereals followed by bitter vetch, lentils, and some flax; and goats, sheep, pigs, and cattle were all raised.

In this study, 60 archaeobotanical samples from three adjacent 10 m × 10 m trenches: LSS 4, LSS 5, and SES 1, were examined to assess the spatial and temporal patterning of the plant remains. The assemblage can be neatly divided into four architectural units, spanning three well-dated phases encompassing the 5.2 k event (Table 1 and Fig. 2). Between 3600 and 3200 BCE, two architectural units were built: the Burnt House and Courtyard area (Trenches LSS 5 and SES 1) with a courtyard and partial room where several pieces of metal, obsidian, and spindle whorls for textile manufacturing were recovered; as well as the slightly later dated Omphalos Building (Trench LSS 4), which, in its final phase, contained numerous vessels, including "Omphalos Bowls," on wooden shelves, all of which were preserved in the subsequent collapse and abandonment. Between ca. 3300 and 3200 BCE, the Southern Courtyard (Trench SES 1) came into use, housing an outdoor activity area with multiple pyric features and evidence that the area was also used for ceramic manufacturing. Both the Burnt House Courtyard and Southern Courtyard contain outdoor activity area spaces with multiple pyric features and associated domestic activities making them easily comparable. Late in the millennium, the Southern Courtyard features fell out of use; beginning around 3100 BCE (Trench SES 1), which dates to the Transitional and Early Bronze phases, this area contained multiple smaller and less well-built mudbrick houses and structures and associated exterior work spaces and refuse dumps, allowing for agricultural practice before, during, and after the climatic and social shifts to be documented.

2. Methods

Sixty archaeobotanical samples spanning four architectural units, representing 12 discrete context types with a focus on pits, pyric features, and surfaces, were selected for analysis (Table 1; von Baeyer, 2020). Twenty-liter sediment samples were collected and floated in the field using a modified Siraf flotation machine with 300 μm mesh light fraction bags and 1 mm mesh heavy fraction screens (Nesbitt and Samuel, 1989). Light fractions were dried in the shade prior to being stored in hard plastic containers. Heavy fractions were sorted in the field and any plant remains were stored with the associated light fraction. All archaeobotanical samples recovered before 2012 were shipped to the University of Connecticut for analysis. Owing to a change in Turkish export laws, samples recovered after 2012 were stored on site and analyzed in Turkey at Bitlis Eren University.

The volume (ml) of light fraction for each sample was measured and the light fraction was separated into four size fractions: >4 mm, 2–4 mm, 1–2 mm, and <1 mm. Each size fraction was then weighed to 4 decimal places (g) and the masses summed to determine the weight of the entire sample. All material >1 mm was sorted in its entirety, while the <1 mm fraction was scanned for any identifiable seeds or plant parts. Cereals were counted following the methods described by Colledge (2001:66). Intact seeds and plant parts were counted as one, as were all culm fragments, rachis fragments, and glume bases. Spikelet forks were counted as two rachis fragments. Dorsal and apical grain fragments were counted separately and the larger of the two counts was added to the count for intact specimens. The total count of small indeterminate cereal fragments that were neither embryo nor apical was divided by 4 or 5 depending on the size of the fragments in each sample, rounded up to the nearest integer, and then added to the count for the intact grains. Fragmented leguminous seeds with both cotyledons present were counted as one. Individual cotyledons were counted, the total count divided by 2, and rounded up to the nearest integer. The number of dung pellets or fragments were also counted and recorded for each sample (Charles, 1998).

Once data gathering was complete, ubiquity (the number of samples within which any taxon is present, expressed as a percentage of the total

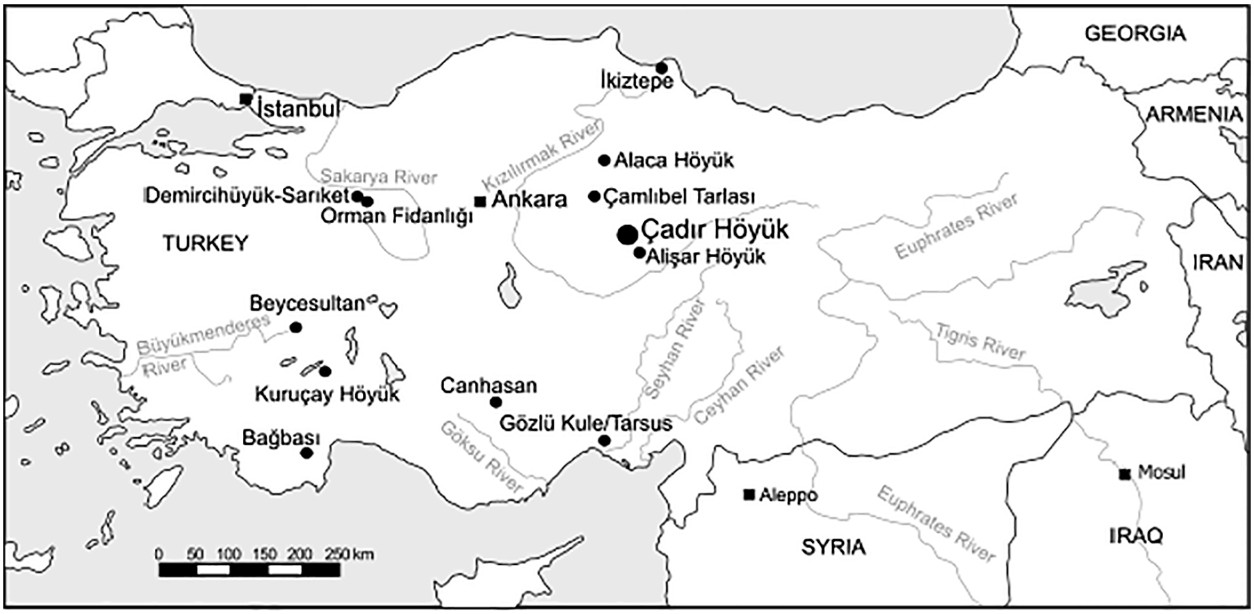

Fig. 1. Map of Anatolia highlighting the location of Çadır Höyük and other Late Chalcolithic Central Anatolian sites.

number of samples), and the relative abundance (the number of specimens per taxon divided by the total number of specimens within a sample or group of samples), were calculated for all taxa within the total assemblage, and within each phase (van der Veen and Jones, 2006).

To assess whether any discrete, in situ remains of cereal processing were present, samples from each architectural unit were plotted on a triangle plot, illustrating the relative abundance of grains, chaff pieces, and weed seeds in each sample. For the samples that had clear pyric associations (i.e. samples from hearths, ovens, kilns, pits, and fill), two ratios were applied to the data to better understand the depositional origin of the remains and assess whether they likely represented the remains of food preparation, remnants of fuel, or mixed assemblages. In order to provide comparison with other studies (Miller, 1997), the ratio of the weight of Non-Woody $>$ 1 mm Plant Parts (weight of the $>$ 1 mm charcoal fraction minus the weight of the $>$ 1 mm wood in a sample) to the weight of $>$ 1 mm Wood fragments was calculated for each sample. Following Miller (1997), the ratio of steppe and wetland weed seeds counts to the number of cereals grains was also calculated. Miller argues that within samples that have a dung fuel origin, this ratio provides insight into animal diet and the extent of grazing. For both ratios, the median values are compared since it cannot be assumed, due to sampling strategies, that archaeobotanical data follow a normal distribution.

Archaeobotanical assemblages from the Burnt House and Courtyard, Southern Courtyard, and Transitional features were examined using correspondence analysis (CA) with Canoco 5.0 to assess spatial and temporal patterning within the dataset. Data from the Omphalos Building were excluded owing to the unusual nature of the deposits, which represented a collapsed shelving unit, and the paucity of remains that the shelves yielded. To further explore patterning in the assemblages, subsets of the dataset (crops, chaff, and weeds) were explored separately using CA. Data were cleaned to reduce the amount of noise in the archaeobotanical dataset following accepted guidelines in archaeobotanical analysis (van der Veen, 1992): samples with fewer than 30 specimens and taxa with less than at least 6% ubiquity were excluded. An additional sample (L102) from a cache context was also excluded owing to its unusual composition. This resulted in a cleaned dataset including 40 samples with 106 taxa. Broken down by plant types: the crops assemblage had 16 samples with 13 taxa, the chaff assemblage had 20 samples with 18 taxa; and the weed assemblage had 33 samples with 79 taxa (Tables provided in SI).

Correspondence analysis (CA) is a flexible, powerful, and open-ended tool for exploring patterning within unimodal ecological or archaeobotanical datasets. As an ordination measurement, CA reduces the dimensions of multivariate ecological data to a few axes that account for variation within the sample (Carlson, 2017; Shennan, 1997; ter Braak, 1996; ter Braak and Šmilauer, 2012). CA orders species and samples along ordination axes, or eigenvectors, that represent theoretical explanatory factors (Shennan, 1997; ter Braak and Šmilauer, 2012). The results can be displayed within a biplot that compares the values from two unrelated eigenvectors. Generally, samples that cluster together have similar contents, and species that cluster together tend to co-occur in samples. The strength of the analysis for each eigenvector is calculated by the eigenvalue (Shennan, 1997; ter Braak and Šmilauer, 2012). While it is possible to view up to four axes within Canoco 5.0, only the first two axes were examined here since they illustrate the bulk of variation within assemblages. Correspondence Analysis was chosen over Principle Components Analysis (PCA) to analyze the data because it allowed the seed counts for each sample to be compared directly and does not require datasets to conform to the normal distribution. PCA is better suited for datasets that require comparisons between standardized data (Shennan, 1997; VanDerwarker, 2010).

3. Interpretative frameworks

3.1. Sample origin

In SW Asia, it is assumed based on ethnographic observations that archaeobotanical assemblages are primarily reflections of food preparation, crop processing, and/or fuel use. To accurately assess changes in subsistence strategies in response to environmental shifts, careful consideration was given to the plant depositional processes in antiquity in order to distinguish samples representing food-based, fuel-based, or mixed origins from one another. To do so, this study relied on three related models to infer the most likely mode of deposition: 1) the range of plant parts found within the products and associated by-products of each crop processing stage observed by Gordon Hillman (1984) following his ethnographic study of non-mechanical free threshing wheat processing in Turkey; 2) Glynis Jones' (1984) study using discriminant analysis to distinguish between discrete crop processing stages based on the size and aerodynamic characteristics of weed seeds; and 3) Charles' (1998) inference of dung use based on the presence of dung pellets, mixed weed seed assemblages representing multiple seasons, and mixed crop processing debris within the same sample. For this study, it was assumed that any large samples with a predominately grain or crop seed composition represented caches related to food use, especially when found in domestic contexts associated with courtyard areas. Any non-cache samples with predominately chaff compositions, the primary type of crop processing debris, or samples that most probably represented pyric debris from hearths, ovens, kilns, pits, and fill, were compared against the models created by Hillman (1984) and Jones (1984) to determine whether the samples could be associated with a specific crop processing stage or whether they represented mixed assemblages. Samples with mixed elements from multiple stages could result from multiple depositional processes, including fuel use, depending on contextual information (Charles, 1998).

3.2. Fuel use

In SW Asia, archaeological and ethnographic data have shown that

Table 1
List of LC Architectural Units with their associated trench, dates, building phases, and number of archaeobotanical samples.[1]

Architectural Unit	Trench	Dates	Çadır Phases	Number of Samples	Context Types
Burnt House and Courtyard	LSS 5	3600–3200 BCE	Early Burnt House Phase	13	Pit Fill, Pyric Feature, Surface, Ashy Fill
Omphalos Building	LSS 4	3400–3200 BCE	Early Burnt House Phase	16	Omphalos Building Shelves, Surface above the Omphalos Building, Surface
Southern Courtyard	SES 1	3300–3100 BCE	Late Burnt House to early Transitional Phase	21	Pyric Feature, Pot Emplacement, Surface, Posthole, Infant Pot Burial, Ceramic Production Area, Cultural Fill, Foundation Trench, Wall Interior
Transitional Buildings	SES 1	3100–2900 BCE	Transitional to Early Bronze I Phase	10	Cultural Fill, Surface, Burial, Pit Fill, Pyric Feature

[1] The building phases used in this article are a simplified version of the official phasing convention used at Çadır Höyük.

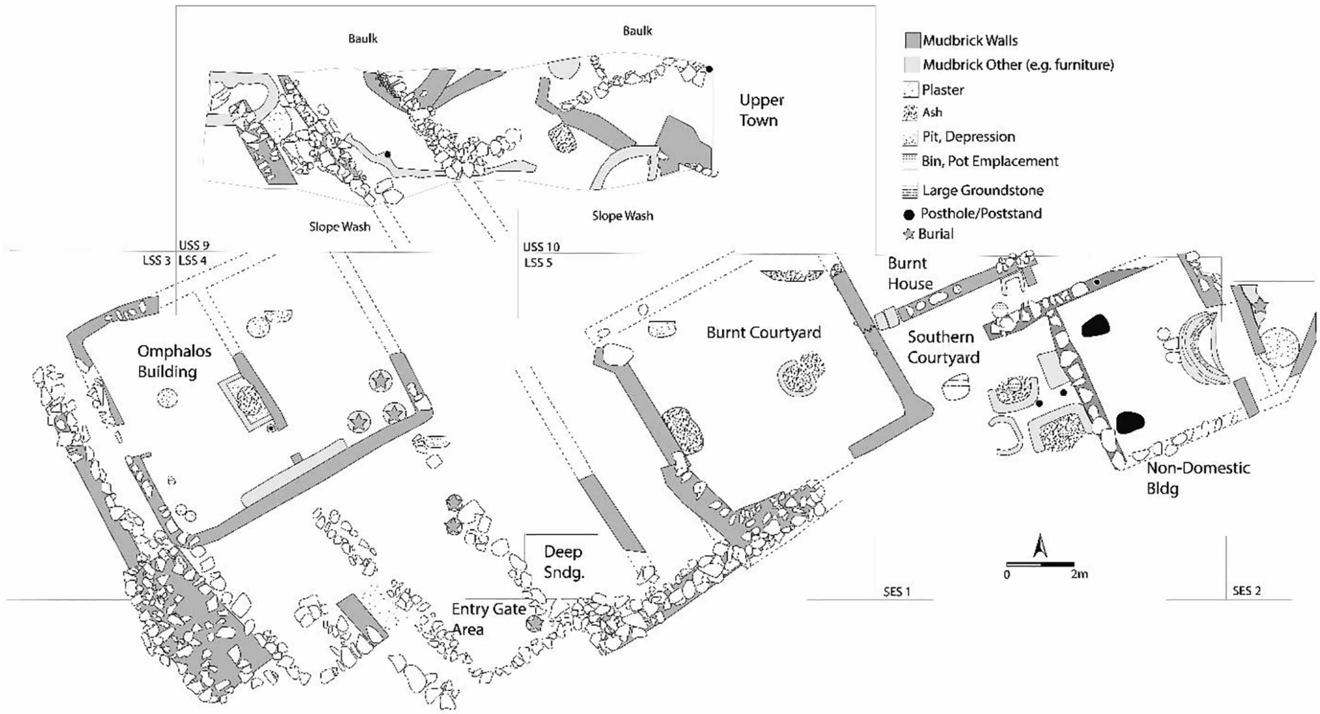

Fig. 2. Plan of the full Late Chalcolithic excavated areas at Çadır Höyük featuring (from west to east) the Omphalos Building, the Burnt House and Courtyard, and the Southern Courtyard.

wood and dung fuel are the most commonly used fuel types. Features with a pyric history, such as hearths, ovens, and kilns can reasonably be expected to contain the remnants of spent fuel. Trash pits are also generally thought to contain fuel waste alongside other household debris. The presence of wood in these contexts provides information on wood procurement strategies (Asouti, 2013; Marston, 2011), and to some degree, environmental conditions surrounding the site (Asouti and Kabukcu, 2014), and land-use strategies (Miller and Marston, 2012). The remnants of burned dung fuel, still a common source of fuel in Turkey, are more difficult to positively identify based on charred plant remains alone owing to the difficulties involved in separating assemblages resulting from crop processing and dung fuel (a summary of the debate is provided by Smith et al. 2019). Multiple approaches have been used to infer dung fuel use. Miller and Smart (1984) were the first to consider the use of dung fuel use in antiquity, suggesting that it would have been used across Southwest Asia at sites where wood fuel was scarce, dung producing animals existed, archaeobotanical remains contained plant species that could have been eaten by a dung producing animal, and the archaeological context of the plant assemblage was indicative of fuel use or disposal. Recently, Allen (2019) suggested that fragmentation ratios of non-wood elements, density measures for a variety of common light fraction elements, and the relative density between charcoal and weed seeds can be used to infer dung use. Smith et al. (2019) have used the existence of dung spherulites in samples to positively identify the presence of dung.

Once the presence of dung has been inferred, it is possible to examine a range of questions that relate to animal diet and fuel use practices. Miller (1988) introduced the use of ratios, primarily the ratio between wood and seeds, to determine shifting reliance on wood fuel or dung fuel through time, arguing that high seed:wood weight ratios indicate dung fuel use (Miller, 1997, 2010, 2013; Miller and Marston, 2012; Miller et al., 2009). Miller (1997) also reasoned that a low ratio of cereal grains represents a high reliance on grazing. If seeds within the assemblages are assumed to have passed through the ruminant animal's digestive tract, we can use the remains to examine foddering or pasturing strategies. By examining the changes in dung composition, it is possible to track small changes in animal diet over time. If animals were predominantly fed through fodder, crop processing debris, and grazing stalks of harvested fields, one would expect the weed taxa to be primarily larger grass weeds that grow in agricultural fields. Grazing fallow fields would result primarily in weeds from species that preferentially grow in disturbed contexts. Finally, grazing in off-site fields would result in a signature composed of weeds reflective of the local surrounding environment; for Çadır it would be steppe weeds.

The preparation of dung for fuel can introduce ambiguity into the archaeological record, however, if one assumes that current practices were similar to practices in the past. Ethnographic work in Turkey has found that dung patties are routinely mixed with crop processing debris as temper (Anderson and Ertug-Yaras, 1998). Both weeds and glumes bases preserve better than cereal grains and other plant parts when digested by ruminants making it difficult to separate crop debris fed to animals as fodder and crop debris added to dung patties as temper (Anderson and Ertug-Yaras, 1998; Spengler, 2019). By observing specimens using a scanning electron microscope, Valamoti (2013) was successfully able to distinguish between plant parts that were excreted within dung versus plant parts that were added as temper.

4. Results and discussion

4.1. Crops

The archaeobotanical results clearly indicate the presence of similar crop and chaff remains in every excavated area and phase, consisting primarily of barley and emmer, lentils and bitter vetch, and a small amount of flax (Table 2). The raw counts for this project are available to download through OpenContext (von Baeyer, 2020). The most abundant crops throughout the second half of the 4th millennium were cereals, which tend to preserve well in the archaeobotanical record. *Hordeum* sp. (barley) was the most abundant crop throughout the assemblage in all phases, followed by hulled wheat, most likely *Triticum dicoccum* (emmer) based on the chaff debris, with evidence for small admixtures of *Triticum monococcum* (einkorn), New Glume Wheat, and *Triticum*

Table 2
Counts, relative abundances, and ubiquity values for crop species.

	Phases B 1–4 3600–3200 BCE (Burnt House and Omphalos)			Phases B–C 3300–3100 BCE (Southern Courtyard)			Transitional Phase 3100–2900 BCE (Transitional Buildings)		
	Count	RA (%) n = 930	Ubiquity (%) n = 29	Count	RA (%) n = 1097	Ubiquity (%) n = 21	Count	RA (%) n = 871	Ubiquity (%) n = 10
Triticum monococcum	24	3	31	3	<1	10	2	<1	10
Triticum dicoccum	22	2	28	3	<1	14	3	<1	20
Triticum durum/ aestivum	5	1	14	0	0	0	1	<1	10
Triticum sp. indet.	55	6	55	72	7	62	27	3	50
Hordeum distichon	0	0	0	13	1	5	8	1	10
Hordeum sp.	164	18	83	172	16	76	223	26	70
Cereal grain indet.	429	46	100	346	32	95	438	50	100
Cereal embryo	5	1	7	15	1	33	65	7	60
Vicia ervilia	28	3	45	19	2	33	12	1	50
Vicia sp.	9	1	17	2	<1	10	3	<1	10
Lens culinaris	46	5	34	298	27	57	22	3	60
Lens sp.	21	2	38	3	<1	14	4	<1	20
Lathyrus sp.	0	0	0	1	<1	5	0	0	0
Lathyrus sp./*Vicia* sp.	0	0	0	0	0	0	1	<1	10
Pisum sp.	2	<1	3	2	<1	10	3	<1	20
Large legume indet.	90	10	97	78	7	86	48	6	90
Capparis spinosa	3	<1	3	0	0	0	0	0	0
Capparis sp.	1	<1	3	7	1	19	1	<1	10
Linum usitatissimum	21	2	21	40	4	38	6	1	30
Linum sp.	5	1	7	17	2	24	4	<1	10

aestivum/durum (free threshing wheat) especially in the earliest Burnt House and Courtyard phase from 3600 to 3200 BCE (Steadman et al., 2019b; von Baeyer, 2018). Grains were observed in most samples, but in small numbers, with the exception of one *Hordeum* sp. cache that has been preserved through a courtyard fire in SES 1. Hulled wheat glume bases maintained high relative abundance and ubiquity values throughout the assemblage (Table 3). A large amount of chaff was recovered from both the Burnt House and Courtyard and Southern Courtyard assemblages, most likely representing on-site processing of emmer spikelets similar to the process observed at Ubaid Kenan Tepe (Graham and Smith, 2013). A similar pattern is evident in the LC archaeobotanical assemblages at Camlibel Tarlasi (Papadopoulou and

Table 3
Counts, relative abundances, and ubiquity values for chaff elements.

	Phases B 1–4 3600–3200 BCE (Burnt House and Omphalos)			Phases B–C 3300–3100 BCE (Southern Courtyard)			Transitional Phase 3100–2900 BCE (Transitional Buildings)		
	Count	RA (%) n = 1132	Ubiquity (%) n = 29	Count	RA (%) n = 2052	Ubiquity (%) n = 21	Count	RA (%) n = 1432	Ubiquity (%) n = 10
Triticum monococcum glume base	14	1	17	72	4	48	64	4	50
Triticum monococcum glume	0	0	0	6	<1	14	2	<1	10
Triticum dicoccum glume base	16	1	28	90	4	38	66	5	40
Triticum dicoccum glume	1	<1	3	1	<1	5	1	<1	10
Triticum dicoccum terminal spikelet	30	3	52	21	1	33	23	2	50
New glume wheat glume base	44	4	31	132	6	33	114	8	40
New glume wheat glume	1	<1	3	13	1	10	5	<1	20
Cereal glume base indet.	573	51	90	1221	60	86	932	65	100
Triticum durum rachis	8	1	7	3	<1	10	4	<1	20
Triticum durum/aestivum rachis	0	0	0	0	0	0	3	<1	10
Triticum sp. rachis	15	1	24	6	<1	10	3	<1	10
Triticum sp. glume	0	0	0	0	0	0	2	<1	10
Hordeum distichon rachis	0	0	0	1	<1	5	0	0	0
Hordeum vulgare rachis	0	0	0	1	<1	5	0	0	0
Hordeum sp. rachis	143	13	62	18	1	24	12	1	40
Hordeum sp. glume	0	0	0	2	<1	5	3	<1	20
Cereal rachis indet.	29	3	38	37	2	43	13	1	60
Cereal glume indet.	22	2	45	108	5	43	55	4	40
Cereal culm (>2 mm) Internode	3	<1	7	12	1	14	2	<1	20
Cereal culm (>2 mm) Node	19	2	31	24	1	38	3	<1	20
Cereal culm (<2 mm) Internode	59	5	55	119	6	71	49	3	90
Cereal culm (<2 mm) Node	124	11	72	103	5	71	52	4	90
Basal culm (>2 mm)	1	<1	3	6	<1	10	0	0	0
Basal culm (<2 mm)	24	2	24	28	1	38	11	1	50
Basal rachis indet.	6	1	7	7	<1	29	5	<1	30

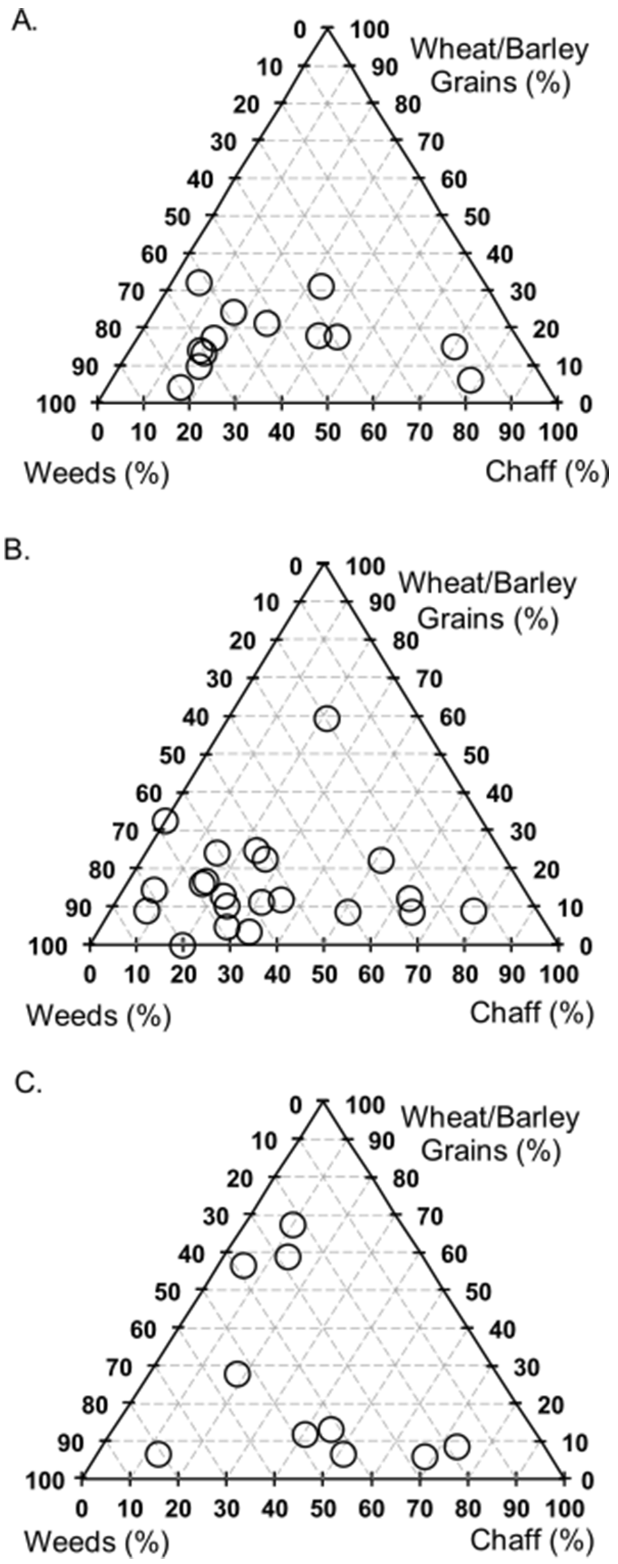

Fig. 3. Triangle plots of samples from the A. the Burnt House and Courtyard, B. Southern Courtyard, C. Transitional area highlighting the relative proportions of grain, weeds, and chaff within samples from each area. Refer to Tables 2–4 for the counts related to each category.

Bogaard, 2011).

Pulses were also important at LC Çadır (Table 2), particularly *Lens culinaris* (lentils) and *Vicia ervilia* (bitter vetch). One cache of lentils was recovered from the Southern Courtyard associated with a pot within a hearth. This was the only context studied that could be interpreted as originating from *in-situ* cooking. The lentils were probably being cooked before the meal was abandoned. *Linum usitatissimum* (flax) was also present throughout the assemblage, often with a similar relative abundance and ubiquity to bitter vetch. It is difficult to discern if flax was primarily used for cooking, medicine, and/or linen production (Valamoti, 2011). There is certainly no indication of what flax was used for at Çadır, although remains of spindle whorls and loom weights were found associated with the Burnt House and Courtyard (Steadman et al., 2008).

4.2. Sample origin

Careful excavations within the Omphalos Building outlined the collapse of a shelving unit that held ceramic Omphalos bowls (Steadman et al., 2007, 2008). Owing to the paucity of the archaeobotanical remains from these samples, the lack of clear association between bowls and plant remains, and the unusual nature of the archaeological context that represented neither crop processing debris nor fuel use, these samples were interpreted as sterile representations of background noise and were omitted from the quantitative measures ($n = 16$). Triangle graphs of grains, chaff, and weeds from the Burnt House (Fig. 3A; $n = 13$), Southern Courtyard (Fig. 3B; $n = 21$), and Transitional areas (Fig. 3C; $n = 10$) created to assess the possible presence of discrete crop processing stages, are shown in Fig. 3. Within these triangle plots, thirty samples were composed primarily of weed seeds with maturation periods spanning several months, ten samples were composed primarily of chaff, and four were composed primarily of grain from the barley cache mentioned above (Fig. 3). Besides the cache, the archaeological context of the samples (i.e., hearths and kilns, pits, and surfaces), had no bearing on the ratio of grains, chaff, and weeds within the sample. Following the sample origin models, all of the chaff and weed dominated samples represented mixed crop processing stages, suggesting that plant remains were routinely combined at Çadır, probably for a variety of reasons. One likely contributor of mixed debris samples was the use of dung fuel that is explored below.

4.3. Fuel use

Samples from pyric contexts (ovens, hearths, pits, postholes, and fill around pyric features) were examined for fuel use. In total, nine samples from the Burnt House and Courtyard were analyzed, alongside 17 samples from the Southern Courtyard, and six samples from the Transitional area. Dung fragments were identified in nine of the 32 pyric samples studied, although no intact sheep/goat dung pellets were recovered. Wood charcoal was present in every sample, even in non-pyric contexts. Wood was present in higher proportions in pyric samples from the Southern Courtyard and Transitional features, while wood was present in slightly higher proportions in non-pyric samples from the Burnt House and Courtyard (Table 5). The presence of more wood in non-pyric samples in the Burnt House and Courtyard can be explained partially by the observed pattern of cleaning out the hearths associated with the Burnt House and Courtyard while the hearths found in the Southern Courtyard and Transitional phases were not cleaned. This suggests that the routines around plant use were stricter in the Burnt House and Courtyard area and phase than in the Southern Courtyard and Transitional areas and phases, a pattern discussed in greater detail in Steadman et al. (2019a). The presence of wood charcoal in contexts associated with fuel remains, as well as the mixed debris found in most samples across all phases indicates that both dung and wood fuel were used at Çadır, although there are no clear distinctions in fuel selection between pyric contexts. Preliminary observations of relatively large numbers of spherulites in a few samples from the Burnt House and Courtyard confirms the use of dung fuel during the earliest phases of this study (Smith et al., 2019). A comprehensive spherulite study on all LC phases a Çadır is planned to assess the relative differences in the presence of dung between samples. Based on the current data, it is believed

Table 4
Counts, relative abundances, and ubiquity values for weeds.

	Phases B 1–4 3600–3200 BCE (Burnt House and Omphalos)			Phases B–C 3300–3100 BCE (Southern Courtyard)			Transitional Phase 3100–2900 BCE (Transitional Buildings)		
	Count	RA (%) n = 2442	Ubiquity (%) n = 29	Count	RA (%) n = 936	Ubiquity (%) n = 21	Count	RA (%) n = 480	Ubiquity (%) n = 10
Ranunculaceae									
Adonis sp.	1	<1	3	1	0	5	0	0	0
Ranunculus arvensis	1	<1	3	10	1	19	2	<1	20
Papaceraceae									
Glaucium sp.	27	1	31	21	2	24	0	0	0
Glaucium type	30	1	14	8	1	33	2	<1	20
Brassicaceae									
Lepidium sp.	1	<1	3	0	0	0	0	0	0
Eruca sp.	0	0	0	1	<1	5	0	0	0
Caryophyllaceae									
Stellaria sp.	33	1	28	17	2	38	14	3	60
Spergularia sp.	2	<1	3	0	0	0	0	0	0
Polycarpon sp.	5	<1	14	6	1	19	2	<1	10
Saponaria sp.	4	<1	10	0	0	0	0	0	0
Gypsophila sp.	0	0	0	2	<1	10	1	<1	10
Silene sp.	16	1	24	40	4	43	9	2	40
Vaccaria pyramidata	6	<1	14	9	1	29	3	1	20
Polygonaceae									
Polygonum sp.	318	13	90	61	7	62	57	12	70
Rumex sp.	4	<1	3	3	<1	10	0	0	0
Chenopodiaceae									
Chenopodium sp.	78	3	66	22	2	43	9	2	60
Malvaceae									
Malva sp.	2	<1	7	4	<1	19	2	<1	20
Malva type	5	<1	10	6	<1	19	2	<1	20
Fabaceae									
Astragalus sp.	34	1	28	29	3	43	22	5	60
Trifolium sp.	110	5	34	61	7	71	30	6	80
Melilotus sp.	68	3	45	109	12	52	48	10	70
Trigonella sp.	25	1	41	14	1	38	8	2	50
Medicago sp.	26	1	17	3	<1	10	0	0	0
Coronilla sp.	0	0	0	5	1	19	0	0	0
Dipsacaceae									
Cephalaria sp.	10	<1	14	4	<1	14	8	2	20
Asteraceae									
Artemisia sp.	0	0	0	1	<1	5	0	0	0
Onopordum sp.	2	<1	7	9	1	19	1	<1	10
Centaurea sp.	9	<1	7	4	<1	19	0	0	0
Boraginaceae									
Rochelia sp.	0	0	0	1	<1	5	0	0	0
Arnebia sp.	26	1	31	57	6	52	25	5	80
Echium sp.	3	<1	3	0	0	0	0	0	0
Onosma sp.	0	0	0	0	0	0	1	<1	10
Lamiaceae									
Ajuga sp./*Teucrium* sp.	15	1	28	6	1	19	5	1	40
Ziziphora sp.	2	<1	7	11	1	19	11	2	40
Thymelaceae									
Thymelaea sp.	54	2	45	41	4	62	23	5	50
Rubiaceae									
Asperula sp./*Galium* sp.	70	3	55	64	7	67	8	2	50
Liliaceae									
Bellevalia sp.	0	0	0	2	<1	5	0	0	0
Cyperaceae									
Bolboschoenus glaucus	26	1	34	6	1	19	2	<1	20
Carex sp.	26	1	7	6	1	19	9	2	30
Cyperaceae indet.	43	2	31	6	1	24	7	1	40
Poaceae									
Eremopyrum sp.	1	<1	3	2	<1	10	0	0	0

(*continued on next page*)

Table 4 (*continued*)

	Phases B 1–4 3600–3200 BCE (Burnt House and Omphalos)			Phases B–C 3300–3100 BCE (Southern Courtyard)			Transitional Phase 3100–2900 BCE (Transitional Buildings)		
	Count	RA (%) n = 2442	Ubiquity (%) n = 29	Count	RA (%) n = 936	Ubiquity (%) n = 21	Count	RA (%) n = 480	Ubiquity (%) n = 10
Aegilops sp.	29	1	38	9	1	29	8	2	40
Hordeum spontaneum	20	1	7	5	1	10	8	2	20
Hordeum wild spp.	0	0	0	4	<1	10	4	1	20
Bromus sp.	508	21	38	16	2	43	11	2	50
Phleum arenarium	18	1	38	25	3	48	5	1	40
Phleum boissieri	13	1	17	17	2	43	9	2	60
Phleum exeratum	10	<1	17	13	1	29	3	1	30
Phleum phleoides	16	1	24	15	2	33	13	3	60
Phalaris sp.	90	4	62	79	8	67	34	7	90
Lolium perenne	22	1	24	0	0	0	0	0	0
Lolium sp.	201	8	76	79	8	76	55	11	70
Poa bulbosa	325	13	14	3	<1	5	3	1	10
Stipa sp.	107	4	52	19	2	43	16	3	50

Table 5
Median values of the wild seed to cereal grain counts by phase, and the > 1 mm wood weight to > 1 mm entire sample weight ratios for fuel, non-fuel, and all samples.

	Phases B 1–4 3600–3200 BCE (Burnt House and Omphalos)	Phases B–C 3300–3100 BCE (Southern Courtyard)	Transitional Phase 3100–2900 BCE (Transitional Area)
Wild seed:Cereal grain Counts Ratio	1.04	1.05	1.37
Non-Woody Plant Parts Weight:Wood Weight Ratio for Fuel Samples	1.89	2.65	3.72
Non-Woody Plant Parts Weight:Wood Weight Ratio for Non-Fuel Samples	1.74	3.70	14.99
Non-Woody Plant Parts Weight:Wood Weight Ratio for All Samples in Phase	1.40	1.65	2.39

the plant remains are indicative of dung fuel use throughout the second half the 4th millennium BCE.

4.4. Change through time

The correspondence analysis (CA) showed interesting temporal trends within the assemblage. While no strong patterns were observed within the full assemblage, it was possible to discern meaningful differences from subsets of the data which can often be the case (Table 6). Correspondence analysis was run separately on the cleaned crop assemblage, the chaff assemblage, and the weedy assemblage from the Burnt House and Courtyard, Southern Courtyard, and Transitional samples (von Baeyer, 2020). Given that each of these components can be associated with different functions and depositional processes, we were able to explore the differences in the dataset with greater resolution. A dramatic change between phases was particularly evident along the primary axis of the CA analysis of weeds (Fig. 4 and Table 6).

Between 3600 and 3200 BCE, the weedy signature at Çadır consisted primarily of large field grasses with seeds that measure over 1 mm long, e.g. *Hordeum spontaneum*, *Bromus* sp., and *Lolium perenne*. In Fig. 4, these species cluster in the upper right quadrant. In contrast, in the later two phases, the weed assemblage is primarily characterized by steppe - grasses smaller than < 1 mm, like *Phleum arenarium*, *Phleum boissieri*, *Phleum exeratum*, *Phleum phleoides*, and *Phalaris* sp. These small grasses cluster in the bottom left (Fig. 4). There is an ecological division between these two groups: the large grass seeds are commonly grown in cultivated fields, while the small grass seeds are not, they grow in the shrubby steppe vegetation surrounding Çadır Höyük (Davis et al., 1965–2000). Considering that most of the pyric samples from Çadır probably originated as dung fuel, assuming the patty manufacturing stayed constant through time, this separation suggests that animal diet, and therefore animal management practices, shifted over the course of the second half of the 4th millennium BCE. Large grass weeds are commonly harvested along with cultivated cereals and can be introduced into animal diets through intentional foddering with grain along with straw, stalks, and other cereal plant parts that are discarded during cereal processing. Small grass seeds, particularly *Phleum* sp. (timothy grass) are grown on fallow fields or away from cultivated fields and indicate increased pasturing, a common extensification strategy in Anatolia (Rosenzweig, 2016). The ratios of weedy taxa to cereal taxa by phase provide additional support for increased animal grazing with a shift from 1.04 to 1.37 between the Burnt House and Courtyard phase and the Transitional phase (Table 5). The exploitation of these ecological zones at different times during the LC at Çadır suggests that there was a shift to increased steppe pasturing or local grazing in last few centuries of the 4th millennium. This suggests that residents were taking animals further afield, away from the settlement for perhaps weeks at a time.

These assertions for increased reliance on grazing in the last few centuries of the 4th millennium BCE are corroborated by the zooarchaeological evidence from Çadır that documents an increase of goats and cattle relative to sheep during the Transitional phase (Steadman et al., 2019b). At the beginning of the Burnt House and Omphalos Building phase around 3600 BCE, sheep were the most abundant caprine species

Table 6
Summary of correspondence analyses conducted on the full, crop, chaff, and weed assemblages from LC Çadır Höyük archaeobotanical data.

Assemblage	Axis of separation by Phase	% Variation of Axis 1	Eigenvalue of Axis 1	% Variation of Axis 2	Eigenvalue of Axis 2
Full	None	8.27	0.125	7.81	0.1180
Crops	Vertical	31.57	0.1951	19.23	0.1188
Chaff	Vertical	20.02	0.1040	17.97	0.0934
Weeds	Horizontal	10.51	0.1510	9.24	0.1326

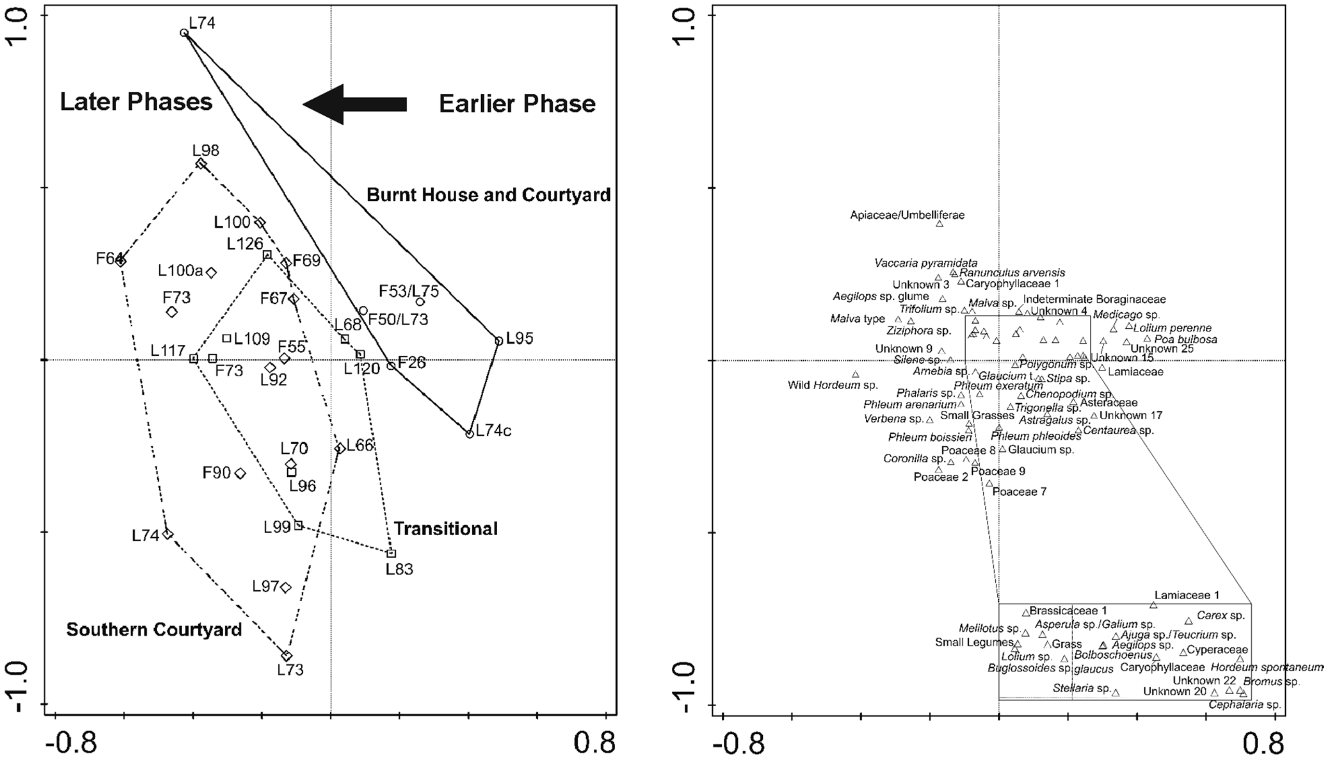

Fig. 4. Correspondence Analysis biplot of the weed assemblage with samples plotted on the left and species plotted on the right from the Burnt House and Courtyard, Southern Courtyard, and Transitional areas with the building phases mapped onto them. The horizontal axis 1 explains 10.51% of the variation with an eigenvalue of 0.1510 and the vertical axis 2 explains 9.24% of the variation with an eigenvalue of 0.1326 for a cumulative total of 19.75% of the variation. The triangles represent species; the circles are samples from the Burnt House and Courtyard; the diamonds are samples from the Southern Courtyard; and the squares are samples from the Transitional area. The species are plotted on the same axes as the samples for easier comparison.

suggesting that the animal economy was primarily focused on producing a surplus of secondary products, primarily wool (Steadman et al., 2019b:40). By the Transitional phase, caprine management shifts from sheep to goats in tandem with an increase in cattle and pigs which has been interpreted as a shift in the animal economy away from specialized wool production towards household animal management and risk reduction (Steadman et al., 2019b:42). A more diversified herd allows for a more secure food base since each animal, cattle, goat, sheep, and pig have slightly different preferences and tolerances for different types of plants and landscape (Dahl and Hjort, 1976). The archaeobotanical evidence from Çadır also indicates a move towards risk reduction which is discussed below.

5. Response to climate change

The archaeobotanical data clearly indicate that at the end of the 4th millennium BCE, animal management strategies shifted to a risk reduction model with diversified herds that were grazed on pasture land. It seems likely that this shift in animal management corresponds to the period of the 5.2 kya event. Overall, the paleoclimate evidence suggests that most of Anatolia was either already in a period of aridity around 3200 BCE or beginning a period of aridity that lasted around 300 to 500 years. The inhabitants of Çadır appear to have adapted to this period of increased aridity by shifting animal management from foddering to grazing which reduced their overall agricultural risk. The risk management strategy of shifting between foddering and grazing animals, has been a common practice in southwest Asia and the eastern Mediterranean since the Neolithic (Halstead, 1987; Marston, 2011; Miller, 2013; Miller and Marston, 2012; Miller et al., 2009; Zeder, 1991). Known as a strategy of diversification (Marston, 2011) or extensification (Boserup, 1965), this approach increases the amount of land used for agricultural and pastoral activities. By increasing the amount of land that is exploited, more wild species of plants grown outside the agricultural boundaries of the site are used to feed animals, which diversifies the overall food base at Çadır making it a more stable strategy. Based on regional evidence for pastoralism in Anatolia, the agropastoral approach at Çadır would have been largely local to the catchment zone around the site as was the practice for most pastoral strategies in central Anatolia during the Late Chalcolithic (Hammer and Arbuckle, 2017).

The median ratio of non-woody plant parts to wood further supports the interpretation that the population of Çadır Höyük adapted to aridity by changing their fuel strategies between 3600 and 2900 BCE. Miller (1997) hypothesizes that dung fuel is used preferentially in arid climates, although a range of cultural factors remain important. At Çadır, the ratio of the weight of non-wood plant parts to wood increased from 1.40 g/g before the 5.2 kya event (the Burnt House and Courtyard phase) to 2.39 g/g to after the 5.2 kya event (the Transitional phase), tentatively supporting intensified dung fuel use over time (Table 5). This ratio can be influenced by a range of factors, including preservation and cleaning, but the presence of spherulites and the composition of the weed assemblage indicate that dung was important.

Given that farming choices are intimately linked with prevailing climate, particularly in semi-arid parts of the world (Smith and Munro, 2009), the 5.2 kya event would have undoubtedly impacted crop yields at Çadır, especially the cereal yields. While farmers can respond to climate change by modifying crop choice, the farmers at Çadır did not appear to do so. Instead, animal management strategies shifted. By shifting to increased steppe grazing during this period of rapid climate change, it was possible to continue to support a large focus on animal management at Çadır Höyük.

6. Conclusion

Around 3600 BCE, farmers at Çadır Höyük maintained a robust agricultural system that focused on cereals, pulses, and flax and animal management focused increasingly on cattle and pig. Foddering and local grazing appears to have been the primary strategy used to provision the animals. Over time, plant and animal management shifted to accommodate more risk adverse strategies. The inhabitants of Çadır continued to primarily grow cereals, possibly with an adjustment towards more barley, and continued to focus on sheep and wool management, but cattle and caprines seem to have been provisioned increasingly through grazing instead of foddering based on the more frequent appearance of small grass grains in dung related the samples. This strategy had the advantage of maximizing the available resources around the site by using land and plants that are not suited for human consumption as a way to generate food (Jones, 1998).

By 3000 BCE, Çadır's farmers had incorporated extensification practices in their agricultural organization as strategy to respond to climate change where animal management focused on provisioning through grazing on the steppe while cereal, legume, and flax cultivation continued largely unchanged. The resource dependency for animal provisioning was spread across a much larger area and through multiple environmental zones in order to compensate for decreased growing conditions brought about by an increase in aridity. By adopting a more flexible subsistence strategy at the end of the 4th millennium BCE, the population at Çadır was able to withstand the rapid climate change they undoubtedly faced. This flexible adaptability was without a doubt one of the key characteristics of the population at Çadır that facilitated the continuous occupation of the site from the Chalcolithic through the Middle Byzantine period.

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Appendix A. Supplementary data

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