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Plants to textiles: Local bast fiber textiles at Pre-Pottery Neolithic Çatalhöyük

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ABSTRACT

Textiles from Neolithic Çatalhöyük are among the earliest and best-preserved *woven* plant artifacts from ancient Southwest Asia. Recent examinations of textiles from Çatalhöyük's East Mound middle habitation phase (6700–6500 cal. B. C.) provide surprising evidence that instead of being made from flax (linen, *Linum usitatissimum*), as previously thought, the fibers are from the inner bark of trees (tree bast), some samples identified as bast from locally growing oak (*Quercus* sp.). The present paper reports on a separate analysis of five woven textile and two cordage fragments, also from the middle habitation phase. Our aims were to identify their raw material origins, distinguish the thread-making technology present, and to situate them within the broader *chaîne opératoire* of thread and textile making in the prehistory of the region. We observed that the thread-making technology was based on an end-to-end splicing method, and while agreeing with the earlier published study, that tree bast, not flax, was the source of the fiber, our results further suggest that elm (*Ulmus* sp.) and willow/poplar (Salicaceae) were also among the bast raw materials used in textile manufacture at the site. From these results we can infer that the textile makers possessed complex understandings of the biology, physiology, and seasonality of local wild tree genera throughout the surrounding environment.

1. Introduction

Prehistoric plant artifacts have a significantly larger importance than their limited archaeological visibility suggests. Twined and woven objects made from twisted and/or plied yarns/threads were undoubtedly integral to the everyday lives of late prehistoric societies; they are therefore key to investigating routines and choices, as well as skills and knowledge, of ancient people. Unfortunately, many factors preclude their recovery and study including the delicacy of their condition, due in part to the processes used to produce them in the first place, as well as the particular conditions necessary for their deposition and preservation, and the specialist techniques needed for their retrieval, identification, and analysis.

Nevertheless, recent increases in the use of archaeobotanical recovery methods such as flotation and improvements in the application of microscopic and other scientific techniques by archaeological textile researchers have established that plant fiber-based artifacts such as woven textiles, baskets, ropes/cords, and twined netting can be recovered and identified. What's more, they provide unique insights into the botanical and ecological knowledge, and specific skills, of thos who manufactured them (Barber 1991; Earwood 1997; Hardy, 2008, 2012; Harris 2014; Rast-Eicher and Dietrich, 2015).

It was, therefore, exciting when evidence of plant-based woven textiles was recovered from a handful of burials at the proto-urban mega-tell of Çatalhöyük. It expanded the geographical range of early Southwest Asian woven plant-based textiles from the Neolithic, around 9,000 years ago, comparable to that of the linen textiles from the 'The Warrior's Cave,' Nahal Hemar in the present-day Israeli desert, dating from cal. 7065 B.C.E. (Schick 1988, 2002; Shamir 2020).

The present article summarizes an analysis of the plant fibers and thread technology of a selection of Çatalhöyük textiles in which we identified several tree basts as the raw materials, expanding the list of arboreal genera known to have been used in textile manufacture at the site. The analysis was primarily undertaken to confirm or rule out flax (linen, *Linum usitatissimum*) as the raw material of the fragments recovered during the 2008 and 2013–15 field seasons (Fuller et al. 2014). The research also aimed to introduce thread technology analysis to situate the materials identified by the team within the broader *chaîne*

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opératoire of thread and textile making in prehistoric Southwestern Asia.

2. The Çatalhöyük textiles

Çatalhöyük is a well-known Pre-Pottery Neolithic mega-tell located in present-day central Turkey (Fig. 1). The site was founded over 9,000 years ago and is composed of two large mounds. The East Mound was occupied for 1,500 years from ca. 7100–5950 cal. B.C. alongside the beginning of early agriculture in the region (Cessford, 2001) and the West Mound from the Chalcolithic, when the population moved across the Carsamba River. Discovered and first excavated by James Mellaart (1964), the site was recently comprehensively studied in renewed excavations by Ian Hodder and his team from 1993 to 2017 (Hodder, 2013). Hodder classified the chronology of Çatalhöyük East into four habitation phases: early (7100–6700 cal. B.C.), middle (6700–6500 cal. B.C.), late (6500–6300 cal. B.C.), and final (6300–5950 cal. B.C.).

Textiles and cordage were first discovered in Mellaart's excavations in Level E VI A/B, which dated to 6200–5800 B.C.E. (Mellaart, 1964). Once these dates were recalibrated and aligned with Hodder's chronology (Cessford, 2001), it was apparent that the textiles from both the Mellaart and Hodder excavations date mainly from the middle habitation phase (6700–6500 cal. B.C.) (Bender Jørgensen et al., 2021; Fuller et al., 2014).

The paleoethnobotanist, Hans Helbæk, made the original examination of the fibers and identified them as wool, due to the fibers' outer margins and scale profiles in microphotography, their elevated levels of nitrogen, the ubiquity of Caprine remains on the site, and the absence of flax in the site's archaeobotanical record (Mellaart, 1964: 101; Helbæk, 1963). Textile historian, Harold Burnham, agreed with Hælbeck's conclusions (Burnham, 1965). Subsequently Michael Ryder recognized them as plant fiber and suggested flax (Ryder, 1965; Ryder and Gabra Sanders, 1985, 1987), which was confirmed by textile specialist Gillian Vogelsang-Eastwood (1988) based on the straightness of the fibers, angular structure of the cell at broken ends and the presence of a lumen, a narrow hallow tube within a fiber cell.

In Hodder's renewed excavation, from the 2008 field season and onwards, textiles were recovered from burials in Buildings 49, 52, and 131 in North Area Level G (6700 and 6500 cal. B.C.). At the time of writing, 28 items have been identified as 'cordage,' 30 as 'basketry' from the 2006–17 seasons alone, and 19 as 'textile' (Bender Jørgensen et al., 2021).

Burials at Çatalhöyük were all intramural, i.e., directly underneath the floors of houses. The small number of textiles that survive were preserved because they were interred in these closed contexts and charred by the indirect heat from the fire, which occurred when houses were deliberately burnt in what appear to be a closing ritual (Boz and Hager, 2013; Nakamura and Meskell, 2013; Russell et al. 2013).

Cordage, basketry, and other worked plant artifacts were also identified from phytoliths (Rosen, 2005; Ryan, 2011; Wendrich 2005; Wendrich and Ryan 2012), and in a few cases as artifacts that were preserved through oxidation by being in contact with metal beads (Bender Jørgensen et al., 2021). Skin and hide items were also found associated with textile artifacts in burials, often serving as an additional layer of a shroud.

Textile finds from Building 52 (Level 4040 G, ca. 6500–6400 B.C.E.) were identified as flax by the archaeobotanical team, citing the fineness and uniformity of fibers (Fuller et al., 2014; Bogaard et al,. 2015). They proposed that, due to the rarity of flax at the site, these linen textiles must have been imported from the Levant or eastern Fertile Crescent (Bogaard et al., 2013; Fuller et al., 2014).

The textiles, often found in association with elaborate burial goods, such as worked Maple (*Acer* sp.) wood and greenstone artifacts (Bogaard et al., 2013; Boz and Hager, 2013; Nakamura and Meskell, 2013), were recovered from burials in houses of the middle-late level, a period in which extraordinary art and installations decorated the houses. This period coincides with the appearance of the deliberate burning of structures as part of closing rituals, the breaking of hard-to-source materials, and the appearance of rarer direct burial goods. The archaeobotany team concluded that imported linens could join the examples of conspicuous consumption (observed at Building 52), reflecting a wider

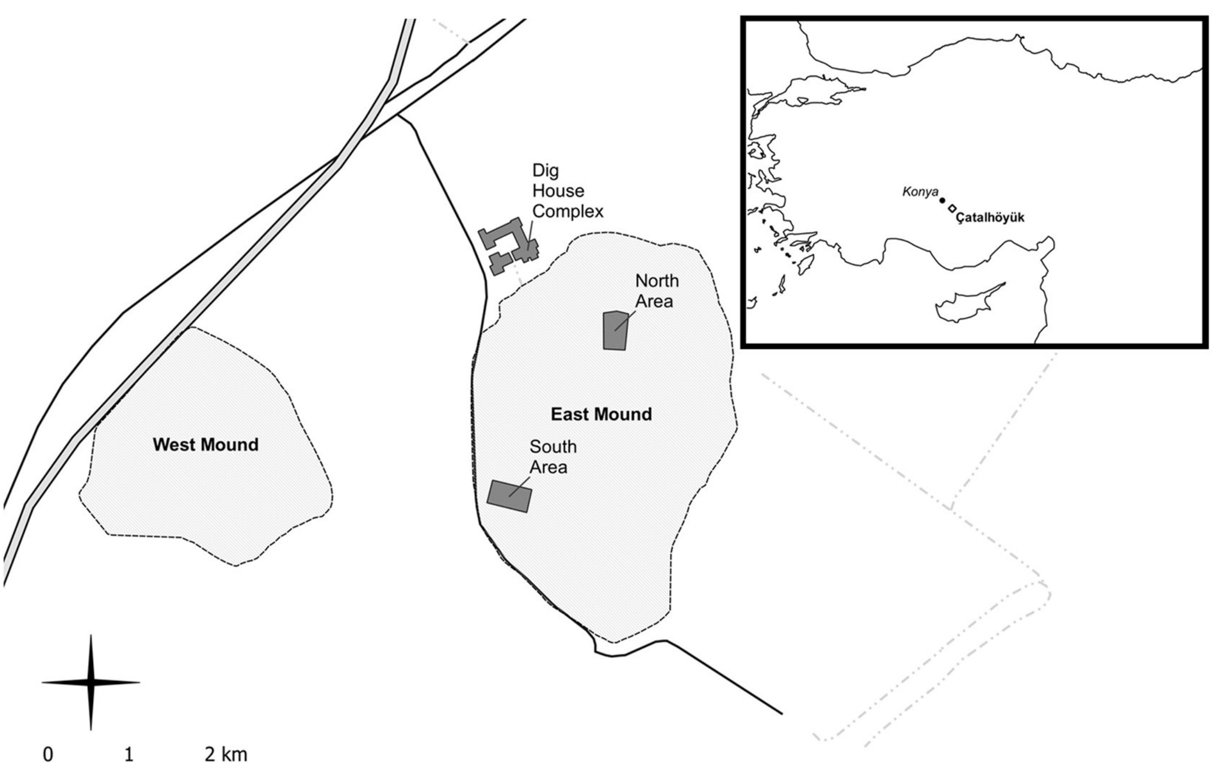

Fig. 1. Site map of Çatalhöyük and regional map of site in relation to the modern city of Konya, Turkey (maps by Nysa Loudon in QGIS).

trend of acquiring high-value materials from an expanding region to the southeast (Baines et al., 2013; Bar-Yosef, 2013; Birch et al., 2013; Carter, 2006; Charles et al., 2013; Twiss et al., 2009).

In 2017, two expert ancient textile specialists, Drs. Lise Bender Jørgensen and Antoinette Rast-Eicher began a comprehensive study of Çatalhöyük's textiles and cordage. Their results refuted previous identifications of flax as the base material of the cordage and textiles, instead identifying oak bast and other unidentifiable tree bast fibers (Rast-Eicher et al., 2021). Moreover, they established that the Çatalhöyük textiles are the earliest direct evidence of weaving (i.e. simple tabby weave with twining border elements), building on twining techniques already established and widespread in Southwestern Asia (Bender Jørgensen et al., 2021).

3. Materials and methods

All fragments of textiles analyzed here are of the woven variety, in which a device such as a loom was used to weave thread making a wider piece of textile. The 'cordage' samples examined here, i.e. twisted and plied ropes/threads that serve as single and separate elements from the larger textile piece, were primarily from burials; they appear to have been used to secure other textiles against the buried body.

All the samples examined here are carbonized. They originate from larger fragments of textiles or cordage recovered from three intramural burials in the North Area of the Çatalhöyük East Mound in the 2008–2015 field seasons (Table 1). The fragments were recovered from grave fill that was processed by flotation by the archaeobotany team or lifted during excavation. Subsamples were exported to London for further analysis.

It should be noted that our research was conducted concurrently with that published by Rast-Eicher and colleagues (2021), and in some cases both studies examined separate subsamples from the same textile origin. Table 1 has an asterisk indicating which samples correspond with those of Rast-Eicher and colleagues (2021), but sub-sampled separately by the archaeobotany team in 2014. Larger textiles or remains of cordage were given a find code and a number associated with their context (for example find X9 is the same as Textile 30503). These larger pieces were then sampled for later study: find X9 had six samples taken, labeled as S5 through S10. These samples have been further subdivided into subsamples for microscopic and SEM evaluation.

Reference materials, used for comparison purposes, were obtained from several sources, including the Institute of Archaeology (IoA) Conservation Lab Fibre Reference Collection, and the Economic Botany Collection at the Royal Botanical Gardens at Kew. Tree bast comparative materials were chosen according to plant family and genera previously identified by charcoal studies at the site (Asouti, 2013) as well as taxa known historically to have been used in woven textiles in neighboring areas (Hamilton and Milgram, 2007; Harris et al., 2017; Hurcombe, 2014; Nagano and Hiroi, 1999; Rast-Eicher and Dietrich, 2015) (Table 2). Unfortunately, we excluded oak bast (*Quercus* sp.) from our comparisons, though identified in charcoal remains at the site, because of its classification by Hurcombe (2014) and Reichert (2006, 2020) as a short bast fiber which can be difficult to twist and unsuitable for fine thread-making. We focused on sourcing tree bast materials to represent families and genera rather than specifically sourcing them from Anatolia, on the presumption that anatomical characters are determined primarily by taxonomic designation, i.e., they are phylogenetically constrained, rather than being determined by geography.

3.1. Laboratory analysis

Samples were examined with Hitatchi S-3400 N SEM at 5. kV with variable working heights, at UCL IoA. Prior to imaging, the subsamples were placed on SEM tabs using carbon cement tape or carbon cement, gold coated, using Quorum Q150RES gold coater, for 90 s. Measurements were made with *ImageJ* software. This examination method was determined primarily due to the carbonization of the samples, rendering cheaper and more accessible technologies, such as a transmitted light microscope or polarized light microscope, unable to observe characteristics due to opaqueness of the samples (Rast-Eicher 2016: 70-71).

The carbonization of these samples made them particularly difficult to work with: the brittleness makes cross-sections for light microscope analysis difficult, if not impossible. Some of the more particular diagnostics for differences between bast fibers, such as remains of rays and cell bodies, and epidermal tissue are more easily visible and identifiable with SEM where the magnification is larger and clearer.

Table 1
Çatalhöyük textiles and cordage sub-samples analyzed in this study. Subsamples originate from larger fragments of textiles and cordage from three intramural burials. All descriptions of samples were taken from the archaeobotany team's identification labels associated with each sample.

Sample	Subsample	Exc. Year	Type	Date	Condition	Area	Building	Associated Fill/burial/skeleton
X10 *	–	2008	Woven textile	cal. 6500–6400 B.C.E.	Carbonized	North, 4040	B.49	F.4023; Juvenile skeleton (Sk17457)
S5 *	S13	2013	Woven textile	cal. 6500–6400 B.C.E.	Carbonized, pseudomorph	North	B.52	Associated with abdomen region of sub-adult Skeleton Sk30511, Burial F. 30503
S10 *	S14	2013	Woven textile	cal. 6500–6400 B.C.E.	Carbonized, pseudomorph	North	B.52	Textile associated with head region of infant skeleton (Sk30511) in Burial 7127
X1. S2	–	2013	Cordage	cal. 6500–6400 B.C.E.	Carbonized	North	B.52	Bandage on skull of subadult (Sk30510), running from top of forehead to bottom of jaw, forming a kind of bandage
S12 *	S3	2015	Woven textile	cal. 6500–6400 B.C.E.	Carbonized	North	B.131	20–30-year-old female, Sk22661. Preserved wrapped around lower leg (tibia and fibula), especially behind right foot
S12 *	S5	2015	Woven textile	cal. 6500–6400 B.C.E.	Carbonized	North	B.131	20–30-year-old female, Sk22661. Preserved wrapped around lower leg (tibia and fibula), especially behind right foot
S4 *	S22	2015	Cordage	cal. 6500–6400 B.C.E.	Carbonized	North	B.131	20–30-year-old female, Sk22661. Preserved across right humerus

* *Source textile or cordage also sampled in Rast-Eicher et al. (2021) study*

Table 2
Comparative Materials sampled from the Institute of Archaeology's Conservation Fibre Comparison Collection and the Economic Botany Collection, Royal Botanical Garden at Kew, London [Collected by Nysa Loudon, August 2019]. Descriptions and identifications originate from collection labels when available.

Catalogue No.	Family	Scientific Name	Common name	Description of Sample	Origin of Sample
Institute of Archaeology Conservation Fibre Comparison Collection, UCL, London					
—	Moraceae	*Broussonetia papyrifera*	Paper mulberry	Stripped fibers	IoA, UCL
—	Linaceae	*Linum usitatissimum*	Flax/linen	Retted and scutched fibers	IoA, UCL
—	Tiliaceae	*Corchorus* sp.	Jute	Retted and stripped fibers	IoA, UCL
—	Cannabaceae	*Cannabis sativa*	Hemp	Dried stem of hemp	IoA, UCL
—	Urticaceae	*Boehmeria nivea*	Ramie	Retted and stripped fibers	IoA, UCL
Collected by Nysa Loudon					
—	Urticaceae	*Urtica* sp.	Nettle	Fresh stem	Gordon Square, UCL, London
The Economic Botany Collection at Royal Botanical Gardens at Kew, London					
64868	Tiliaceae	*Tilia europeae*	Lime tree	Fibrous inner bark	Prince Liechtenstein (Moravia)
64855	Tiliaceae	*Tilia vulgaris*	Lime tree	Rope made from bark	?
64867	Tiliaceae	*Tilia cordata*	Lime tree	Inner bark and rope of fiber	Japan
64854	Tiliaceae	*Tilia europeae*	Lime tree	Plaited bast	?
41363	Salicaceae	*Salix artica* Pall.	Willow	Fishing net and string or inner bark	Canada
42212	Salicaceae	*Salix alba*	Willow	Willow bark	UK-Pharmacology Society of Great Britain
41391	Salicaceae	*Salix cordata* Muhl.	Willow	Twisted bark	Canada
41340	Salicaceae	*Populus tremuloides* Michx.	Aspen	Bark of Aspen	USA
41335	Salicaceae	*Populus balsamifera* L	Cotton wood	Cordage of bast	British Columbia, Canada
43540	Ulmaceae	*Ulmus* sp.	Elm	Mandul or Hill Shoes	?
42175	Ulmaceae	*Ulmus campestris*	Elm	Inner elm bark/cortex	Museum of Pharmacology Society of Great Britain

3.1.1. Identification criteria

Bast fibers are notoriously difficult to differentiate because of their similar botanical morphology (Bergfjord and Holst, 2010; Lukešová et al., 2017; Suomela et al., 2018). The most useful observable diagnostic features in bast identification (used in conjunction) are: lumen size and shape, fiber thickness, microfibril orientation, radial (surface) appearance, and presence/absence of other related cell bodies, for example pitting, cell plates, crystals, and the remains of (inner bark) rays (Bergfjord et al., 2012; Bergfjord and Holst, 2010; Catling and Grayson,1982 [1989]; Cook, 2001; Florian et al., 1990 [1992]; Gale and Cutler, 2000; Khalili et al., 2002; Kirby, 1963; Petraco and Kubic, 2004; Ryder and Gabra Sanders 1985, 1987; The Textile Institute, 1975). Guidance for tree bast identification on ray appearance and associated cell bodies was sourced from Oktaee et al. (2017), Rast-Eicher (2016), and Rast-Eicher and Dietrich (2015), alongside collected and imaged reference material from Kew. The online database *Inside Wood* (*InsideWood* 2004-onwards; Wheeler, 2011) was consulted for information on specific tree Family/genera classification characteristics, with which to compare cell bodies, plates, and/or rays observed within the Çatalhöyük fiber samples.

Reference materials (Table 2) were cut to 1 cm length and mounted on SEM tabs, gold coated for 90 s, and imaged using the SEM. Because the reference materials were from modern and/or historic collections, the fibers were pliable enough to be cross-sectioned with a sharp safety razor blade, then embedded between two pieces of polyethylene with acetone, or simply stood up on one end on SEM tabs with carbon tape.

A 'dry twist' test, to find microfibrillar orientation (S or Z twisted), was applied to the tree bast reference materials provided by Kew based on The Textile Institute's (1975) methodology. The microfibrillar orientation, a key difference among economically important domesticated fibers (Bergfjord and Holst, 2010; Lukešová et al., 2017; Suomela et al., 2018), has not been observed for tree bast species. In some SEM photos, microfibrillar orientation can be discerned in the archaeological material from breakages or worn edges of the fibers. This diagnostic feature, used in conjunction with others, can narrow down the Family/genus of the archaeological material.

3.2. Technological analysis

Thread-making technology (i.e., spun or spliced) was determined according to criteria defined by Gleba and Harris (2018). Spliced describes a thread-making technique that has been identified in many prehistoric plant-based threads in Europe, North Africa, South America, and Southwest Asia (Barber, 1991; Beresford-Jones et al. 2018; Gleba and Harris, 2018; Granger-Taylor, 1998, 2003; Leuzinger and Rast-Eicher, 2011; Rast-Eicher, 2016; Rast-Eicher and Dietrich, 2015). Unlike spun thread, spliced threads describe lengths of plant fiber being tied or twisted together, end-to-end, and then sometimes plied together. This is denoted as S2*I, as in two spliced single lengths that are S-plied (after Bender Jørgensen et al., 2021).

The angle of ply and twist were measured using *ImageJ* software on SEM generated images. SEM imaging was used to observe other more microscopic criteria, such as lined-up fiber-cell nodes and leftover cell bodies/epidermal tissue that indicate splicing techniques.

4. Results

Results of study are summarized in Table 3, with an expanded report on results in the following subsections, divided by context of samples.

4.1. Level North G, 4040 Area, Building 49, Unit/Skeleton 17457, (cal. 6500–6400 B.C.E.), excavated 2008

Sample X10.

This textile sample was identified as elm bast (*Ulmus* sp.). The sample consisted of four pieces of brown, carbonized, 2-plied yarn made of strips of plant bast, distinguished as plant by its lack of scales and the cross dislocations along the length of the bast (Fig. 2.A). The yarns are likely spliced, rather than spun, due to the smooth, ribbon-like appearance of the bast with aligned dislocations and distinct bundles of fibers (Gleba and Harris, 2018) thread technique S2*i, or two spliced roves plied in an S orientation. Previous identifications of this yarn as flax (Fuller et al., 2014) were called into question by the presence of

Table 3
Çatalhöyük sample results and descriptions analyzed in this study.

Sample	Context	Technique	Building	Results
X10	Unit 17457, F.4023; Sk (17457)	Two S plied yarn, with two Z twisted (clockwise) spliced lengths or S2*I; loose angle of twist (<45°)	B.49	Carbonized; fiber thickness: 8 μm-19 μm; remains of thin, possibly uniseriate medullary rays; circular to polygonal cross-sections with varied wide and small lumen, medium to thick cell wall; 'Z' twisted microfibrils; possible lamination in cross-section, perhaps the higher lignin secondary layer identified by Oktaee et al. 2017 in willow bast; collapsed vessel ray with distinct bordered pitting, characteristic of surveyed *Ulmus* sp. **Identified as: Elm (*Ulmus* sp.) bast**
S13. S5	Unit 30503; F.7127 Sk (30511)	Woven textile; tabby; S2*I; loose angle of twist (<45°) w/ tightly twisted (>45°) intervals	B.52	Carbonized pseudo-morph; Fiber thickness: 4 μm-22 μm; oval and very flat, elongated kidney shaped cross-sections, lumens no longer exist; dislocations and cross-markings visible in the pseudo-morph cast of fibers; very deteriorated microscopically. **Identified as: Indeterminate bast fiber**
S14. S10	Unit 30503; F. 7127 Sk (30511)	Woven; 4-ply yarn; S4*I	B.52	Carbonized pseudo-morph; Fiber thickness: 3 μm-16 μm; kidney, circular, and ovular cross-sections; possible remains of thin medullary rays; dislocations and cross-markings visible in the pseudo-morph cast of fibers; very deteriorated microscopically. **Identified as: Indeterminate bast fiber, possible tree bast?**
X1.S2	Unit 30503; F. 7127 Sk (30510)	Cordage; loose (<45°) single S twisted length	B.52	Carbonized; no individual separated fibers; simple oval perforation along the radial view of the cordage; large lumens and thin walls. **Identified as: Oak (*Quercus* sp.) bast?**
S3.S12	Unit 22661 Sk (22661)	Subsample of woven textile 22661; S2*I yarns	B.131	Carbonized; fiber thickness: 2 μm-29 μm; plausible rays; long ovular or polygonal cross-sections; large variety in size of lumen and cell wall thickness, generally medium to wide; clear cell layers in cross-section of fibers (Oktaee et al. 2017); 'S' twisted microfibrils; remains of a parenchyma cell wall; possible remains of uniserate medullary rays between fiber lengths. **Identified as: Salicaceae (poplar/willow) tree bast?**
S5.S12	Unit 22661 Sk (22661)	Woven textile fragment (folded) and 3 S2*I yarns of Textile 22661;	B.131	Carbonized; fiber thickness: 7 μm-28 μm; very polygonal or long ovular fiber cross-sections; small to large lumens; plausible voids from long, thin medullary rays that contribute to 'flat' look on the fibers; cross-sections have noticeable layers to them (Oktaee et al. 2017); 'S' twist to microfibrils; heavily degraded by fungus. **Identified as: Indeterminate tree bast**
S22.S4	Unit 22661 Sk (22661)	Cordage; single length; no twist in this sample	B.131	Carbonized; straight, lightly processed fiber bundles; very large fiber lumens; lots of silica skeletons with simple circular perforations; possible remains of pitted vessels-rays of *Quercus* sp.; Remains of phytoliths and silica skeletons alongside bast lengths. **Identified as: Oak (*Quercus* sp.) bast? Mixed indeterminate plant cordage?**

associated structures not usually found in flax: i.e. remains of perforation plates and rays. While dislocations are discernible, they are not as thick as in flax, and the samples contained plausible remains of rays (associated ribbons of parenchymal cells that are aligned radially within a tree) typical of tree bast (Rast-Eicher and Dietrich, 2015; Rast-Eicher, 2016). In Fig. 2.D & E, arrows indicate the remains of a collapsed perforated vessel-ray, featuring distinctly bordered pitting. Of the possible bast producing trees known to be local to Çatalhöyük (Asouti 2013, 2017; Bogaard et al., 2013; Charles et al., 2021), only elm has perforated vessel-rays with distinctly bordered pitting (*InsideWood* 2004-onwards; Wheeler, 2011). Rast-Eicher and colleagues identified this fiber as 'plant fiber,' as their sample was heavily mineralized and degraded (2021).

Alongside the remains of this perforated vessel ray, in a particularly deteriorated area along the length of one fiber, there are visible 'z' twisted microfibrils, also uncharacteristic of flax (Bergfjord and Holst, 2010). This sample shows an odd phenomenon where there is a structure around each fiber, most noticeable in transverse view, which resembles a loose tube (Fig. 2.B). This suggests the remains of a higher lignin outer layer such as that in willow (*Salix* sp.), identified by Oktaee and colleagues (2017) and in other tree bast species by Loudon during SEM analysis (Fig. 2.C for an *Ulmus* sp. example), adding further weight towards an identification as tree bast.

4.2. Level North Area G, Building 52, Unit 30503, (cal. 6500-6400 B.C.E.), excavated 2013/14

Subsample S13 of Sample S5, Subsample S14 of Sample S10, and Sample X1.S2.

Subsamples S13.S5 and S14.S10 were identified as an indeterminate plant bast. They are from larger samples associated with a woven textile find X9 (Textile 30503). The biggest sample in this study, S13.S5, is tabby weave (Fig. 3). The other sample, S14.S10 is a twisted yarn, the only one to be 4-plied (Fuller et al., 2014). The twist and ply direction of both samples follow that of the previous example where the spliced roves (un-plied thread) were given a loose additional twist and then plied clockwise.

S13.S5 (the woven textile) has thick yarn, about 1 mm, woven perpendicular to a thinner (about ½ to ¾ mm) yarn. The loose ply, paired with small instances of a tighter twist (45–50 degrees) points to an end-to-end splicing thread-making technique (Gleba and Harris, 2018) (Fig. 3.A). Both samples are mineralized and pseudomorphs (Fig. 3.B), resulting in a negative cast where the disintegrated fibers used to be (Gleba and Mannering, 2012; Unruh, 2007).

Because of the poor condition of these samples, we could only conclude that both were made of plant bast fibers based on the imprints of cross dislocations with a mostly smooth texture along the length. The spores and hyphae of the fungus *Chaetomium* (Kvavadze et al., 2009) are very frequent across both textile pieces, contributing to the deterioration of the fibers.

Rast-Eicher and colleagues (2021) identified their subsamples of this textile (S6-S9) as possible oak bast, based on the remains of a perforated vessel. Their sample appears to be in better condition than the samples examined here, which illustrates how much preservation varies across even one textile piece. Their SEM photo of the sample (2021: 8) exhibits a pitting with distinct borders within the identified deteriorated vessel ray. The fiber is tree bast but the distinctly bordered pitting in vessel rays is not common in oak, which more often features simple pitting (*InsideWood* 2004-onwards; Wheeler, 2011). We otherwise suggest elm bast (*Ulmus sp.*) is more likely than oak because of the type of pitting present

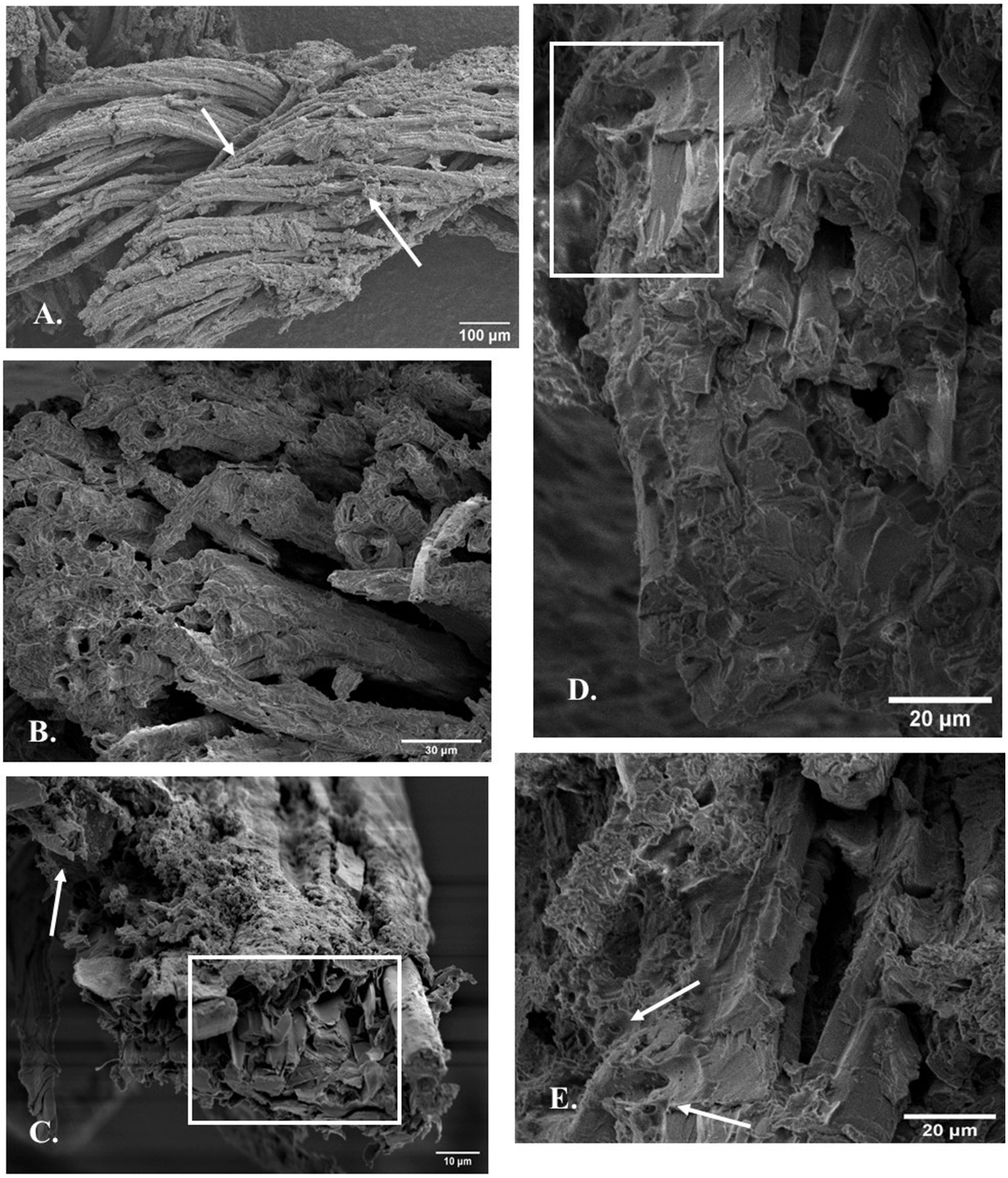

Fig. 2. Sample X10, found in context Burial Unit 17457: **A.** Arrow points to the remains of thin rays between fiber bundles; **B.** Depicts the 'glove-like' texture surrounding the fibers, most notable at the ends of the piece in transverse view; **C.** An ethnographic example of *Ulmus* sp. illustrating a similar 'glove-like' or double layered phenomenon (EBC, Kew Cat. No. 43540); **D & E.** Arrows point to distinct bordered pitting in the remains of a vessel-ray in sample X10 leading to the suggested ID of *Ulmus* sp. or elm bast.

in that image.

Sample X1.S2 is from cordage that formed a kind of bandage around Skeleton 30510. The sample has a slight 'S' twist, resulting from its manufacture as tree bast cordage. There are no distinct perforation plates visible to permit a definitive identification of genus or species. However, the similarity of the large lumens of the fibers with that of Rast- Eicher and colleagues' sample S4 of cordage 30511 (2021: 6, Fig. 2), identified by them as oak bast, suggest that Sample X1.S2 could also be oak.

4.3. Level North Area G, Building 131, Unit 22661, (cal. 6500–6400 B.C.E.), excavated 2015

Subsample S3 and S5 of Sample S12 and subsample S4 of Sample S22.

Characteristics found in both subsamples of Sample S12 point to the identification of tree bast, with features that suggest the Salicaceae (willow/poplar) family. Both S3.S12 and S5.12 subsamples are from a sample of the larger textile (sample S12 of Textile 22661). S3.S12 consists of three pieces of S2*i yarn of loose ply (Fig. 4.A). Subsample S5. S12 includes one tightly S plied yarn (45–50 degrees) from two spliced roves (S2*i) and a piece that shows the tabby weave, folded under itself

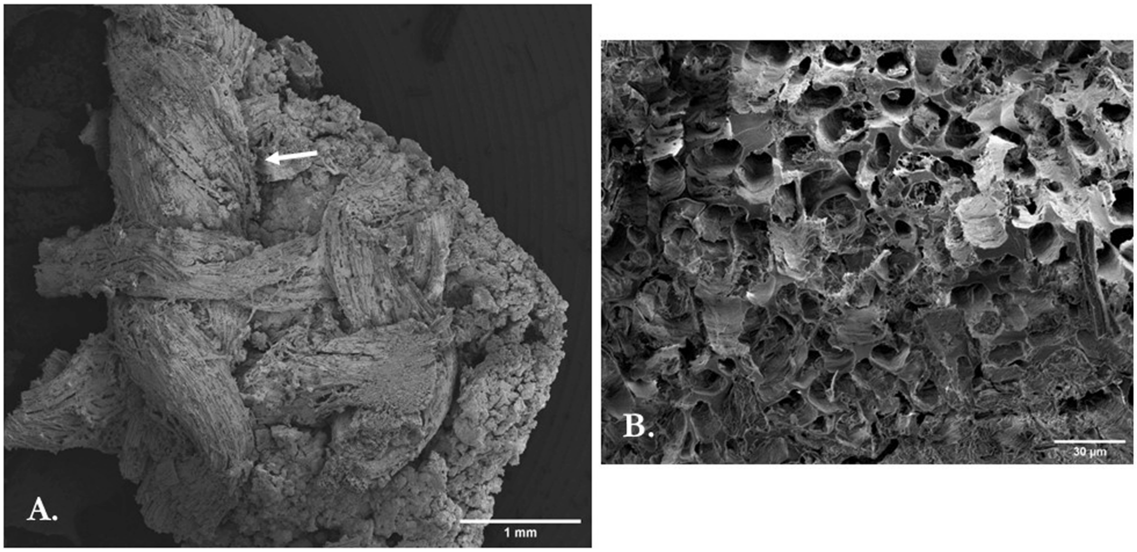

Fig. 3. Subsample S13 of Sample S5 (S13.S5) associated with the burial of several individuals in B.52: **A.** Arrow indicates the tighter twisted ply surrounded by loosely twisted plies that indicates end-to-end splicing thread technology (Gleba and Harris 2018) **B.** Image taken in transverse view, detailing the mineralized pseudomorph where empty holes exist where deteriorated fibers once were.

with various angles of ply (Fig. 5.C).

Fiber bundles in both subsamples have plausible rays along their length and a 'flatness' to the overall yarn that disintegrates into the finer fibers at the ends (Fig. 4.A & Fig. 5.A). This texture is similar to the charred and waterlogged textiles found in the German lake-dwelling settlements identified by Rast-Eicher (Rast-Eicher and Dietrich, 2015: 35). Fibers have a wide range of thicknesses with an approximate mean of 12 μm. S3.S12′s fibers have a 'woody' or 'fluffy' texture along the length compared, for example, to the generally smooth surface of flax (Fig. 4.B). The apparent 'uniform fiber thickness' that Fuller and colleagues (2014) observed when viewing with a light microscope can be seen to be much more variable than generally found with flax, when seen under SEM (5–21 μm, with a mean of 10 μm (Ryder and Gabra Sanders, 1985, 1987)). The remains of a simple pitted perforated vessel can be seen along the length of one of S3.S12′s fibers (Fig. 4.B).

In subsample S3.S12, there are plausible cell bodies similar to those found in comparative studies with *Populus* sp. (Fig. 4.C) which are uniseriate and simply perforated. In S5.12 the deterioration of a fiber end shows the microfibrils have an 'S' or clockwise twist (Fig. 5.D). The results of dry twist tests done as part of the comparative research, showed that poplar bast samples had 'Z' or counterclockwise twisted microfibrils, while willow (*Salix* sp.) samples had 'S' or clockwise twisted microfibrils. This suggests that the sample is more likely willow than poplar. However, most of the cell bodies are far too degraded for this identification to be confident. This is a common problem with tree basts that have small rays, during manufacture these thin rays are more likely to be processed out and to collapse during deterioration (Rast-Eicher 2016: 85). Because distinctly bordered pitting is not present in these samples and the perforated vessels noted are small, unlike oak bast, the bast is likely a Salicaceae species, or another fine tree bast.

S22.S4, is a sample of cordage (Fig. 6), identified here as tree bast, possibly oak (*Quercus* sp.). Another sample of the same cord was examined by Rast-Eicher and colleagues (2021) and identified as oak bast, due to the presence of a large simple perforation plate and large lumens. The sample examined in this study was less well preserved but also showed plausible remains of rays, large lumens in fiber bundles, and associated pitting found in radial sections of oak bast. There are remains of some phytoliths and silica skeletons within pieces of the sample, but not throughout, suggesting that multiple species were used in the manufacture of the cordage (Fig. 6.C).

5. Discussion

In the study of ancient textiles broad attention has been given to domesticated fibers, chief among them wool and flax, as key prehistoric economic fibers for textiles in the Western world (Barber, 1991; Bar-Yosef, 2020; Becker et al., 2016; Breniquet and Michel, 2014; McCorriston, 1997). In recent years, more awareness of non-cultivated bast's role in prehistoric textile cordage and netting has been championed by textile experts (Earwood, 1997; Rast-Eicher and Dietrich, 2015; Hardy, 2008, 2012; Harris, 2014; Reichert, 2006, 2020).

Bast fibers, stripped from the stems/trunks of plants, are the oldest evidence of fibers for cordage, twined fabrics, and textiles across the prehistoric world (Barber, 1991; Bar-Yosef, 2020; Hurcombe, 2014; Kvavadze et al., 2009; Schick, 2002; Shamir, 2020). Because of where this type of bast originates in a plant/tree, differentiating between economically important bast fibers in archaeological samples is incredibly difficult, giving rise to many identification studies over the years (Bergfjord et al., 2012; Bergfjord and Holst, 2010; Catling and Grayson, 1982 [1989]; Cook, 2001; Florian et al., 1990 [1992]; Gale & Cutler, 2000; Lukešová et al., 2017; Khalili et al., 2002; Kirby, 1963; Petraco and Kubric, 2004; Ryder and Gabra Sanders, 1985, 1987; Suomela et al., 2018, to name a few).

Tree bast is a sclerenchyma cell associated with a tree's living cambium layer, lying just under the inert bark layer of the tree (Cutler et al., 2008). Though all trees have these cells, particular genera in Eurasia, such as willows (*Salix* sp.), poplars (*Populus* sp.), lime/linden (*Tilia* sp.), elms (*Ulmus* sp.), birch (*Betula* sp.), and oak (*Quercus* sp.), have lent themselves towards producing longer and more easily harvestable bast fibers (Hurcombe, 2014; Reichert, 2006, 2020; Schoch, 2015). Tree bast requires a different skillset to turn it into fine thread than an herbaceous stem bast like flax due to its higher lignin content and position within the plant. Regimes of harvesting and processing would rely on knowledge of the longer growth patterns of arboreal flora and different extensive cultivation tactics to reliably harvest new growth and maintain the ecologies that supported chosen fiber species.

Of the five examined samples of woven textiles and two of cordage we identified almost all as tree bast. Our results confirm Rast-Eicher and colleagues' (2021) conclusions about the Çatalhöyük broader textile collection, that, unlike their neighbors to the southeast, residents of this mega-tell used local upland and wetland tree basts, not flax.

While we agree with Rast-Eicher and colleagues (2021) that oak bast

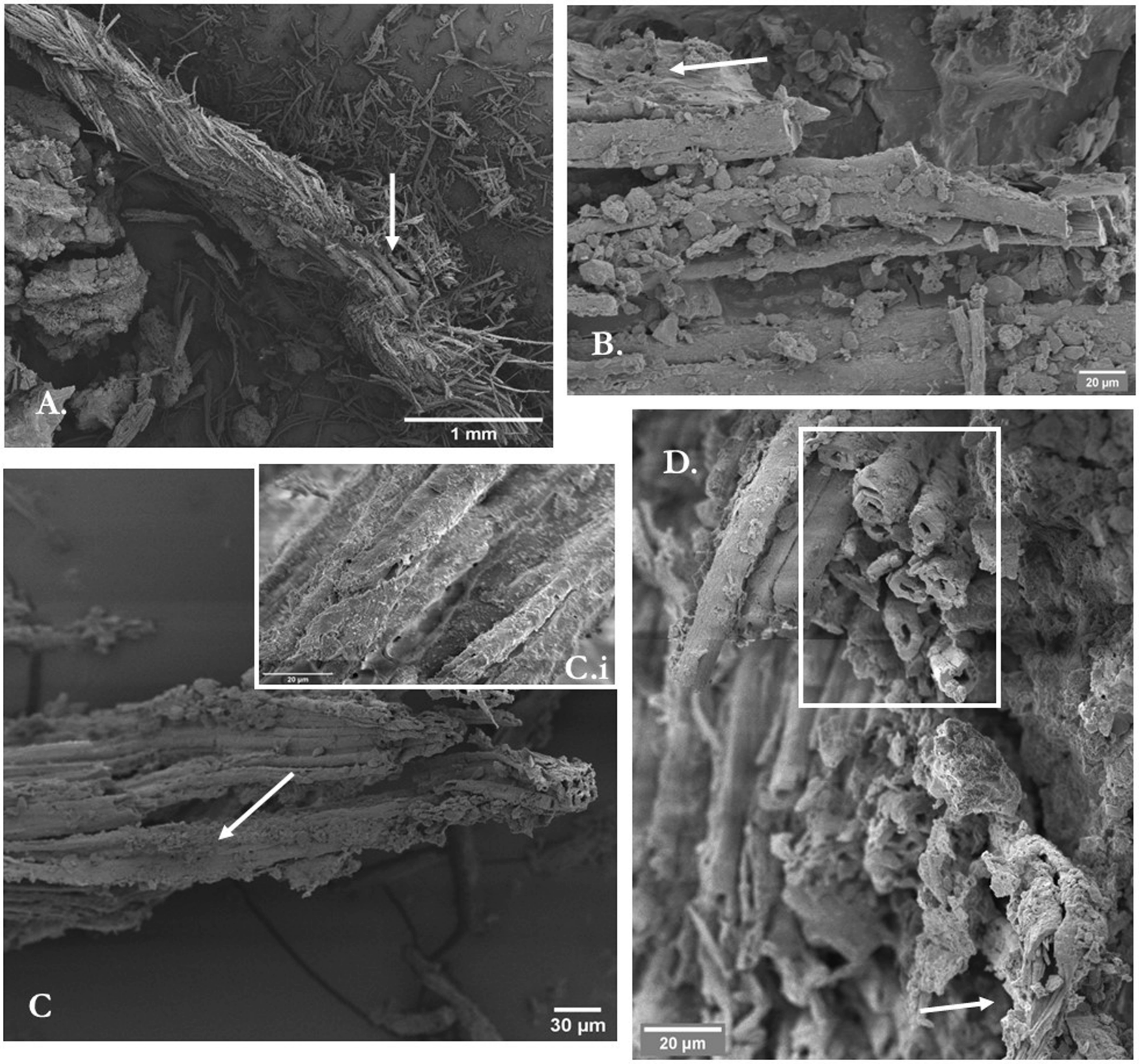

Fig. 4. Subsample S3 of S12 (S3.S12), textile remains associated with the burial of Skeleton 22661 in B. 131: **A.** Arrow points to the remains of medullary rays running along the length of the fiber bundles; **B.** Arrow points to simple pitting found alongside fibers leading to the identification of tree bast; **C.** Arrow points to pitting in possible uniseriate vessel rays (greatly deteriorated), **C.i.** Ethnographic sample of *Populus balsamifera* (cottonwood), (EBC, Kew Cat. No. 41335) showing an example of pitting in uniseriate vessel rays; **D.** Arrow indicates section where the twist of the microfibrils are visibly 'S' shaped, box highlights fibers have distinctive layers in transverse view.

fibers and tree bast were raw materials used in textile manufacture at the site, our results further suggest that elm and Salicaceae basts were also used. We base our argument on the presence of distinctly pitted perforated vessel-rays and thin ray spaces and that X10 and the subsamples of S12 are both of finer quality than those of S22.S4 and X1.S2, the latter two identified as oak bast cordage. These characteristics might suggest further specialization in the qualities of bast material, where residents used finer tree basts such as those in elm and Salicaceae for finer woven textiles and oak bast for coarser cordage. The presence of Salicaceae charcoal at the site provides evidence that the trees in this family were known to and used by the residents, so it is not unlikely that they exploited the bast as well as the wood. Çatalhöyük was located in a wetland landscape, and thus willow and riparian elm can be expected to have been readily available adjacent to the site, while oak, would have been obtained further away on better drained soils, but with some still within the local catchment (Asouti and Kabukcu, 2014; Ayala and Wainwright, 2020; Ayala et al., 2022).

Tree bast thread-making and weaving are among the growing list of craft specializations known from the mid-later levels of the Çatalhöyük (Wright, 2014). The picture that then emerges is a diverse set of locally foraged fiber plants being exploited for very specific reasons alongside an expanding early agriculture. The skilled working of various tree basts found in a single neighborhood, North Area, Level G, suggests an experienced *chaîne opératoire* of thread-making. Moreover, a range of plant families and genera appear to have been used, alongside those for basketry and matting regimes, such as grasses and sedges identified by phytolith evidence (Rosen, 2005; Ryan, 2011).

5.1. Ecological evidence

Fiber foraging can be added to the Çatalhöyük resource 'taskscapes' (Ingold, 1997; Wolfhagen et al., 2020). From the Çatalhöyük seed and charcoal records we know that residents routinely collected wild plants, herbaceous and arboreal, from all environmental zones of the surrounding Konya plain (Asouti 2013, 2017; Fairbairn et al., 2007; Ayala et al., 2022; Wolfhagen et al., 2020). Asouti (2013, 2017) discussed the

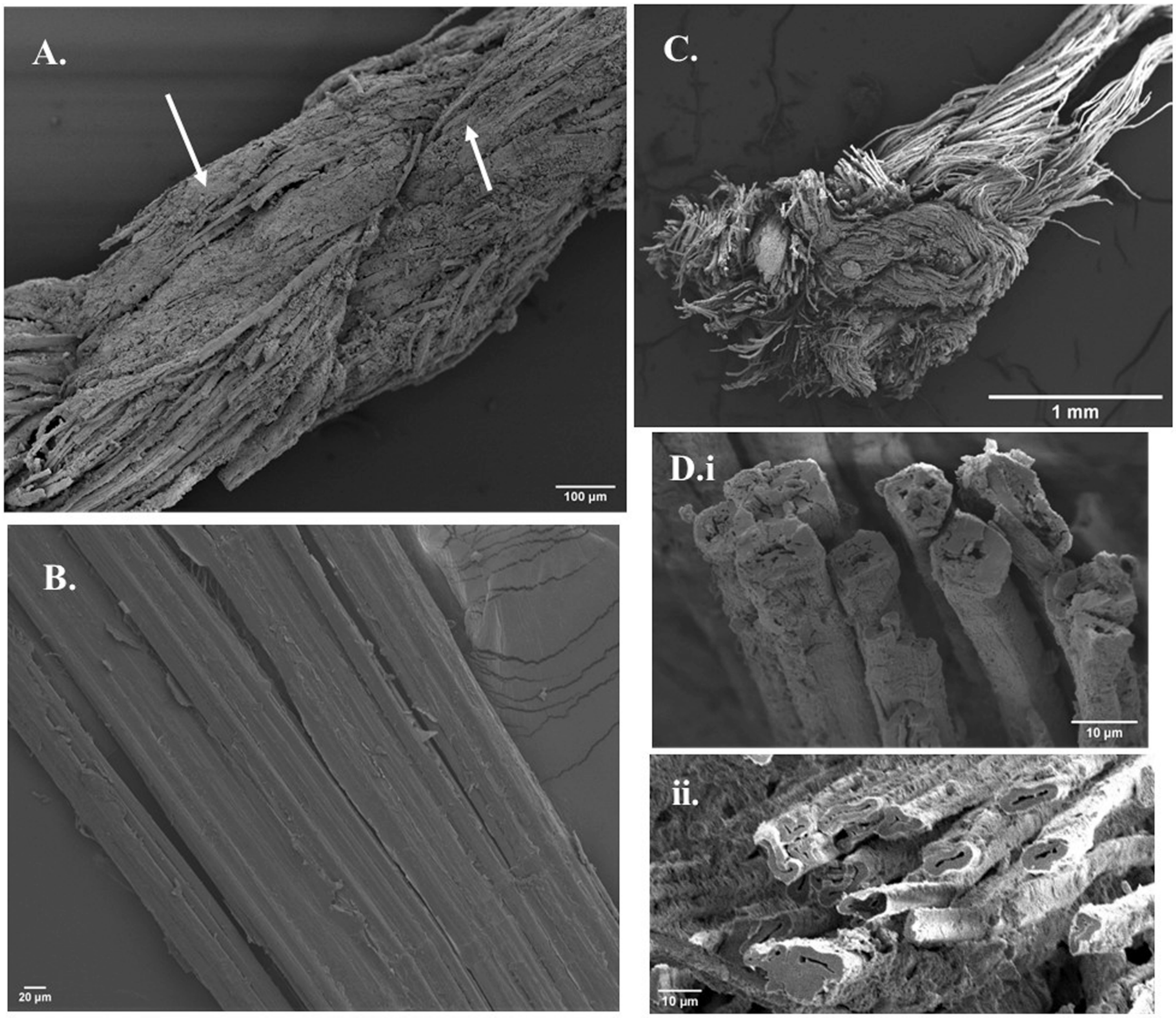

Fig. 5. Subsample S5 of Sample S12 (S5.S12): **A.** Arrows indicate possible remains of medullary rays along the length of the bundles, texture of the surface is thick and flat unlike flax; **B.** *Linum usitatissimum* (Flax), retted and scutched fiber prepared for UCL Institute of Archaeology Conservation Fibre Comparison Collection, pieces of related cell structure and epidermis still attached to these fiber bundles from its shorter processing, but remain mostly smooth in appearance **C.** Overall picture of folded textile fragment, sample has loose plying and the remains of a tighter twist which could indicate end-to-end splicing thread technology; **D.i** S5.S12 fibers in transverse view and **ii.** S3.S12 fibers in transverse view showing large variation in size and shape of fibers and lumens.

activities and skilled ecological knowledge that underpinned routine wetland and upland tree exploitation and management practices. Of particular interest here is Asouti's discussion of the pollarding of oaks, evident from defoliation in charcoal assemblages (2013). This is a common technique used to encourage long, thin, new growth and, significantly for the present study, a practice in which tree bast fiber and/or basket making materials can be routinely and sustainably gathered (Harris, 2014; Hurcombe, 2014; Myking et al., 2005; Oktaee et al., 2017). Asouti's forest management evidence supports Rast-Eicher and colleagues' (2021) identification of oak bast, as this could be the technique used for consistent bast extraction alongside the other identified uses of oak wood at the site, primarily as house support beams and firewood (Asouti, 2013, 2017; Asouti and Kabukcu, 2014).

Mixed caches of burned twigs, generally Ulmaceae (elms) and Salicaceae (willow or poplar) were recovered from flotation samples. Asouti (2013) theorized that they were likely woodworking debris associated with carved wood artifacts found in both the Hodder and Mellaart excavations (1964). She observed that the *Ulmus* sp. twigs were harvested in the winter after six years of growth, and, of particular interest here, that Salicaceae was harvested after one to two years, in the spring when the resin in parenchymal cells is rising (Asouti, 2013: 140-141) which is the time in the tree's annual cycle that it is easiest to separate the inner bark from the rest of the tree's cambium layer (Rast-Eicher, 2016: 81; Pfeifer and Oeggl, 2000; Hurcombe, 2014; Harris et al., 2017; Reichert, 2020). It is therefore possible that these mixed caches include bast fiber processing debris.

5.2. *Tree bast* ***chaîne opératoire*** *at Çatalhöyük*

Tree bast, though a stiff fiber, can be processed into finer threads for making woven fabrics using a sequence of steps involving peeling the inner and outer bark in strips from the trunk or branches of a tree then soaking, boiling, beating, or scraping to release the layers of bast, and finally separating the fibers by hand or with a heckle. Based on ethnographic and historic observations of non-mechanized tree bast collection and processing, we can envisage a scenario in which Çatalhöyük residents removed tree bast from thin branches or in strips from the trunk of the tree during the spring, when the sap rose, which they then further processed by possibly soaking, boiling, and/or beating the bast layer to separate the inner bark fibers. The true bark would then be scraped off and split fine by hand (Gleba and Harris, 2018; Hurcombe, 2014; Karg, 2011; Reichert, 2020).

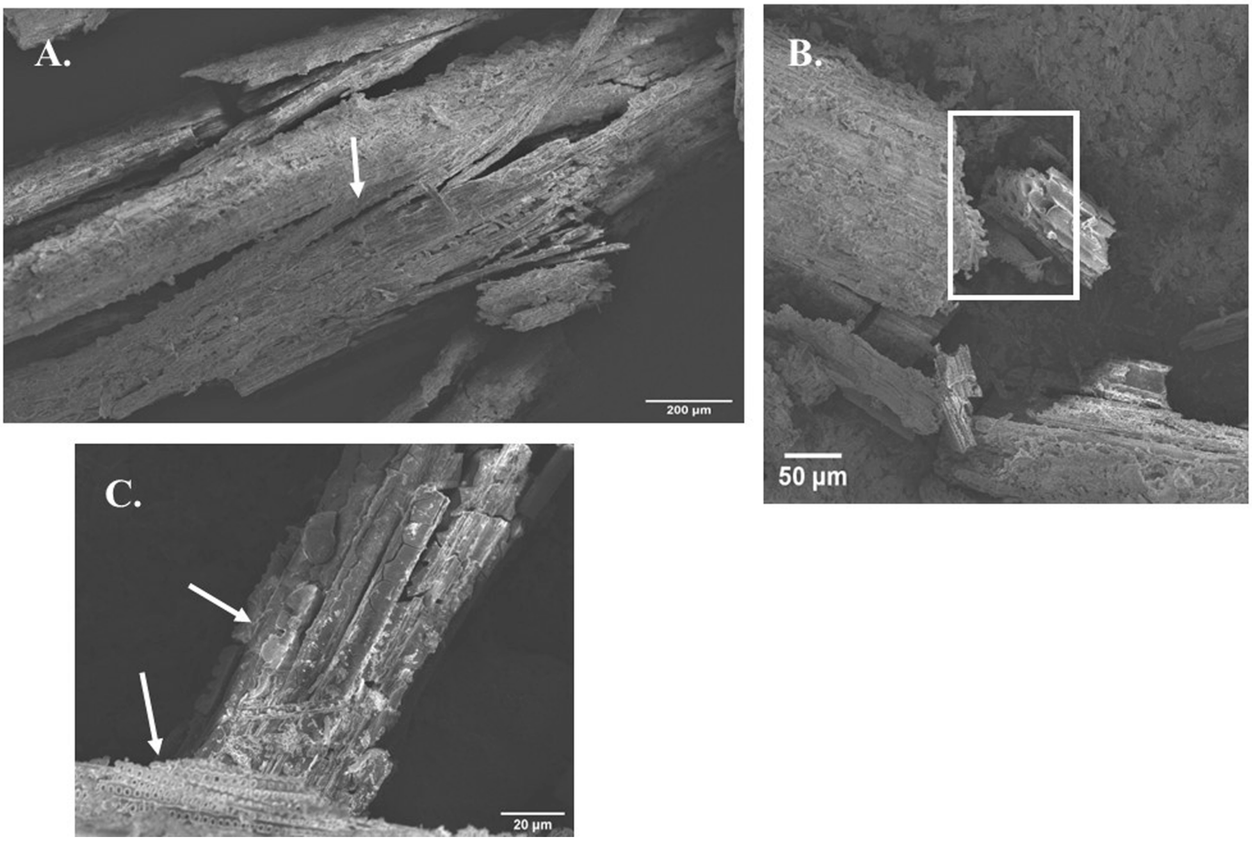

Fig. 6. Subsample S22 of Sample S4 (S22.S4), cordage found across the right humerus of Skeleton 22661 in B.131: **A.** Sample still retains ‘S’ twist, arrow indicates example of the remains of medullary rays along the length of the sample; **B.** Wide lumens and thin cell walls of fibers, a characteristic also noted by Dr. Rast-Eicher and colleagues (2021) in oak bast (*Quercus* sp.) **C.** Arrows point to various phytoliths found alongside the bast and the remains of plant silica structures.

And end-to-end splicing technique, in which the fibers were spliced base-to-tip is evident in Sample S13. S10. Among all the textile samples that we examined, only this sample was complete enough to exhibit ‘end-to-end’ thread splicing (refer to Nagano and Hiroi, 1999 for more information on this technique; and Gleba and Harris, 2018 on archaeological textile technique interpretation).

Though these steps seem simple, the process to making tree bast into a fine and pliable material requires strength, skill, a large investment in time, as well as a significant knowledge about the appropriate arboreal species for producing fine thread, and times of year that they are best collected (Hamilton and Milgram, 2007; Hurcombe, 2014; Nagano and Hiroi, 1999; Reichert, 2006, 2020). The tabby weave in these textiles suggests that a technology for weaving was available. Prehistoric looms are typically a set of parallel twigs holding the warp taught, allowing for picking up every other thread by either picking or through a simple shuttle (Nagano and Hiroi, 1999).

5.3. Archaeological and historical use of Oak, Elm, and Willow/Poplar bast

Tree bast has a long and diverse history of usage around the world, as one can glean from worldwide archaeological, historical, and ethnographic accounts (Bernick, 1998, Pojar and Mackinnnon, 1994 (Northwest Coast, North America); Earwood, 1997 (Northern and Central Europe); Hamilton and Milgram, 2007; Lennard and Mills 2020; Nagano and Hiroi 1999 (East Asia and Pacific Islands); Médard, 2006; Rast-Eicher and Dietrich 2015 (Neolithic and Bronze age Circum-Alpine pile-dwelling settlements); Oktaee et al., 2017 (Africa)).

Historically, willow has mostly been used in Northern Europe for basketry and cordage (Harris, 2014; Harris et al., 2017; Oktaee et al., 2017; Gale and Cutler, 2000), but the bast can be fine enough to be used in textiles (Hurcombe, 2014: 30-31). Other genera in the Salicaceae family have also been used around the world as viable fiber options: Poplar species (*Populus* sp.) such as cottonwood (*Populus balsamifera*)) was used in North America by prehistoric and historic Indigenous peoples (Hurcombe 2014: 30). Northwest Coast native peoples are well known for their historic and ancient uses of red and yellow cedar (*Thuja plicata* and *Chamaecyparis nootkatensis*) and bitter cherry (*Prunus emarginata*) in textiles and basketry (Pojar and MacKinnon, 1994).

While further research is needed to establish its use in Europe, *Ulmus* has been a viable bast option for numerous populations across the world. The use of elm in textiles is ethnographically documented in Japan (Nagano and Hiroi, 1999), particularly among Indigenous Ainu communities in Northern Japan, where tree bast fiber has been in use to make ceremonial kimonos (*Robe*, T.99–1963). The Haudenosaunee (commonly known as Iroquois) in the New York region have also been recorded as using slippery elm (*Ulmus fulva*) (Hurcombe, 2014: 30). There is a brief mention of elm bast being used in Europe alongside lime, oak, and willow by Harris (2014: 3) and Hurcombe (2014: 31).

Oak bast has been found archaeologically in the Swiss Neolithic and Bronze Age Lake pile dwelling sites alongside lime tree and flax finds (Rast-Eicher and Dietrich, 2015; Médard, 2006). The bast has been used in basketry, cordage, and shoes (Rast-Eicher, 2016: 85; Rast-Eicher and Dietrich, 2015: 62, 80; Pfeifer and Oeggl, 2000). Unlike both elm and Salicaceae bast, most experimental studies of oak bast’s properties as a fine fiber find that, although it is a good insulator (Hurcombe, 2014: 31) and can be easily peeled off the tree during the spring (Schoch 2015), it is difficult to twist without breaking and is not suitable for fine thread-making (Reichert 2006: 26, 2020: 167; Hurcombe, 2014: 31).

6. Conclusion

Çatalhöyük residents were shown to have had the skills to transform stiff lignin tree bast fibers into thin fiber ribbons that they subsequently spliced into fine thread for textiles. Elm (*Ulmus* sp.) and willow/poplar (Salicaceae) tree basts were identified from archaeological fragments recovered from enclosed burials. The craftsmanship, in fact the earliest known weaving the region, indicates a high degree of skill as well as a complex understanding of the botanical and physiological properties and seasonality of specific tree genera. The shrouds and their related cordage further reveal new dimensions to the residents' interactions with wild and foraged species surrounding the tell, which they expressed through craft technologies and material culture related to the intramural burial of their dead. Our results support and augment those of Rast-Eicher, Karg, and Bender Jørgensen (2021). Çatalhöyük's textiles and cordage are in fact tree basts. Rather than importing their fiber from the southeast, as previously thought, residents developed their own unique, local, and environmentally specific, foraged tree-bast textile craft. The presence of weaving and specificity of local plant fiber use in the middle habitation phase at Çatalhöyük suggests that archaeologists can explore the possibility that the knowledge and material traditions in textile making originate earlier than this in prehistory.

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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Further reading

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