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The role of plants and fibres in modelling monumental terracruda sculptures of the Silk Roads: archaeobotanical analyses from the Buddhists sites of Tepe-Narenj and Qol-e-tut (Kabul, Afghanistan)

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Abstract
This work presents the results of archaeobotanical examinations of fragments of monumental *terracruda* sculptures from the Buddhist sites of Tepe Narenj and Qol-e-tut (Kabul, Afghanistan—5th to eleventh centuries CE). The results indicate that different plants and parts of plants were intentionally added to the clay mixtures. In particular, we identified an extensive presence of bast fibres, which were not evidenced by macroscopic examinations and previous analyses. Among the fibres, we highlight the presence of ramie/nettle, whose use has been identified for the first time in this type of artworks. The determination of these herbaceous additives offer a new perspective for studying the manufacturing technique, as well as an anchor point to follow this tradition along the Silk Roads. It also provides relevant information that should be taken into account in the design of conservative interventions adapted to the specific nature of this heritage.

Keywords: *Terracruda* sculpture, Clay, Archaeobotany, Phytoliths, Fibres, Silk Roads, Heritage conservation

Introduction

X-ray Micro-Computed Tomography (TAC) analysis [1] on sculptural remains from the archaeological site of Tepe Narenj (Afghanistan) highlighted the presence of herbaceous material in the clay-based modeling pastes. These results opened the issue of what type of herbaceous material was used and whether its use was random or followed a specific pattern necessary for the elaboration of this type of monumental artwork. In this paper we present the first results of phytoliths and fibres analysis of different sculptural and mural fragments coming from the archaeological sites of Tepe Narenj and Qol-e-tut (Kabul, Afghanistan) (Table 1). We investigated whether herbaceous plant tissues (e.g., leaf fragments, stem fragments, etc.) were present in the clay used to model the sculptures of Tepe Narenj (fifth-tenth centuries CE) and Qol-e-tut (sixth- eleventh centuries CE) sites, and if so, whether it was possible to identify the species used. This constitutes a relevant information, not only for the understanding of the elaboration method and its adaptation to the different regions where this artistic and spiritual tradition of modelling the divine figure in raw earth was established in antiquity, but also to envisage whether a better or worse state of conservation of historical examples could be related to the use of herbaceous additives of different origin. This information could help to select

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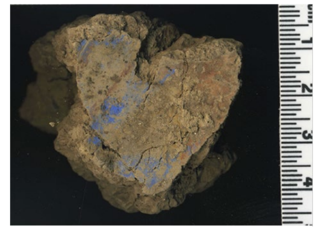
Table 1 Fragments analysed, samples ID and description

Fragment	ID	Description	Picture
TN1	TN1	Clothing fragment recovered from a basket deposited on the central pedestal of Chapel 1. Modelled with greyish brown clay (Munsell 10YR 6/3) and finished with a thin layer of whitish stucco. Maximum length: 83 × 54 × 48 mm. According to archaeological data, it had been recovered from the stratigraphic remains pertaining to mid-sixth century CE	
TN2	TN2-int	Possible halo or niche arcade fragment with incised decoration recovered from a basket placed inside the Chapel 1 above the stone socle of the south wall. According to archaeological data, it had been recovered from the stratigraphic remains pertaining to the to mid-end sixth century CE. Maximum length: 97 × 53 × 39 mm. 3 layers: -Very pale brown inner layer (Munsell 10YR 7/3) with a lot of vegetal imprints -Immediately above, a more homogeneous modelled layer of very pale brown colour (Munsell 10YR 7/3) -Surface layer of remarkable hardness, between 5 and 7 mm thick, of quite homogeneous red colour (Munsell 2.5YR 5/6)	
	TN2-ext		
	TN2-nucleus		
TN3	TN3	Possible internal body fragment in contact with wooden structure located on Chapel 3 sculpture number 4-north. According to archaeological data belonging to the first or third period of occupation (5th to early eighth century CE). Made of greyish brown clay (Munsell 10YR 6/3). Maximum length of 89 × 62 × 37 mm	
TN4	TN4	Possible clothing fragment deposited in a basket located inside Chapel 4 and archaeologically dated to the end of the 6th—beginning of the seventh century CE. Maximum size: 84 × 63 × 30 mm. A Single layer of greyish-brown clay (Munsell 10YR 6/3) with a red polychrome finish (Munsell 2.5YR 5/6). Due to its morphological characteristics, it could be a sculptural fragment or a mural decoration in relief	
TN6	TN6	Wall fragment (in contact with the back side of the sculptures) of Chapel 4 (end of the 6th—beginning of the seventh century CE)	
TN7	TN7-int	Finger fragment from a basket located in Chapel 5 (mid sixth century) with 3 layers distinguished macroscopically: –TN7-int light brown clay layer (Munsell 7.5 YR 6/4) –TN7-ext greyish-brown clay layer (Munsell 10YR 6/3) –White stucco surface 1 mm thick	
	TN7-ext		

Table 1 (continued)

Fragment	ID	Description	Picture
QT1	QT1	Mural sample (finished with blue and ochre): Fragment preserved in a basket in front of the sculpture of the Great Buddha located in Chapel 13 consisting of a single layer based on yellowish greyish brown clay (Munsell 10YR 6/4) with a surface finish made with the same type of clay. On this finish the colours, a few microns thick, are superimposed	
QT2	QT2	Clothing fragment preserved in Chapel 13 in the same basket as QT1, placed at the foot of the "Great Buddha" and belonging to its robes. The figure has been archaeologically dated to the middle of the eighth century CE. Maximum length 78 × 40 × 29 mm. From its macroscopic study, 5 layers can be distinguished starting from the exterior: –Pale red polychrome (Munsell 2.5YR 7/6) of only a few microns –A layer of high-density white stucco of approximately 1 mm –Possible presence of fabric (detected in some points by 8 × magnifying glass) –Lower density and very porous white stucco layer, which tends to separate from the layer immediately below –The bulk of the fold is based on very pale greyish-brown clay (Munsell 10YR 7/3). This layer preserves in its base numerous traces of having been in contact with a stratum or surface with a high presence of plant additives	
QT3	QT3	Sample of north wall of the Chapel 13	
QT4	QT4	Toe fragment preserved near the remains of the left foot of a sculpture inside Chapel 6 archaeologically identified as a bodhisattva and dated to the mid-sixth century	

a suitable material with similar functions, to be used in repair mortars, following compatibility and sustainability conservation criteria.

The practice of modelling monumental *terracruda* sculptures

The practice of modelling monumental *terracruda* sculptures is an artistic tradition that presents no known examples outside of South, Central, and Eastern Asia. These sculptures can be smaller than human size or reach several meters in height. They are skilfully modelled in situ starting from a core skeleton of wood, brick or stone attached to a background, shaped with different clay-based layers, frequently covered with a white layer lime-based, gypsum-based or kaolinite-based usually referred as “stucco” and, finally, polychromed and/or gilded [2–4]. Historic examples of this artistic expression are mainly linked to the spread of Buddhist art from the northwest of the Indian subcontinent through what is known today as the ‘Silk Roads’. The first Buddhist instances are found in the area of present-day southern Uzbekistan, Tajikistan, Afghanistan and Pakistan linked to the world-renowned "Greco-Buddhist Art" or "Art of Gandhara" (ca. 1–8 centuries CE). Later, they spread to the Himalayas and Eastern Asia, where examples can be identified up to modern times.

Scientific analyses carried out so far have usually focused on investigating the mineral and chemical composition of the pastes and polychromies [5–9]. Conversely, the method employed to model the sculptures that usually exceed human size, where the use of herbaceous material mixed within the earthen mortars would play a fundamental role, has been little evidenced scientifically [1], even less by analytical studies that allow us to understand what taxa or part of plants were used.

Recent studies [10] have shown that the elaboration method used in the past could be very similar to the one used today in some areas of India, such West Bengal, where an ancient caste of clay-artists continues to produce monumental *terracruda* idols following a century-old tradition described in several Sanskrit ritual texts, the oldest dating to the eighth century CE [2].

These texts mention the addition of coconut fibres in a ratio of 1:4 in the last stage of processing the earthen mortars into suitable modelling pastes, and cotton fibres, in the finishing layers; nowadays, Bengali artists use different parts of the rice plant (chaff, husks) or jute fibres in a similar ratio using one or the other herbaceous material varying on the layer or body element to be modelled [10] in order to produce stickier, lighter or smoother pastes depending on the layer, with a lower shrinkage to favour a better drying process. Consequently, knowing what kind of herbaceous material, plants or parts of plants were added to one sculpture at each stage of work according to the layer to be formed in the entire modelling process, seems fundamental. This will allow conservators to design specific repair clay-based mortars for archaeological sculptures that fulfill the same function and that can accomplish the current conservation criteria, based on the compatibility and sustainability of the materials used for conservation or restoration purposes.

In this context, interdisciplinary collaborative research is being carried out to fully understand the elaboration process and the materials used to make monumental terracruda sculptures. The main aim is to develop new conservation strategies, better adapted to the specific nature of these works of art that, to date, continue to be inspired by treatments designed for other types of artworks, such as terracotta or earthen mural paintings.

Tepe Narenj and Qol-e-tut

The sites, separated by ca. 400 m. and located on the route that connected the historical regions of Gandhara and Bactria (or, in other words, India with Central Asia), are laying on the eastern slopes of the Hindukush Mountain chain, only a few kilometres from the south of the present-day city of Kabul, overlooking the natural lake of Qol-e-Hashmat Khan (Fig. 1).

According to previous archaeological research, directed by the franco afghan archaeologist Z. Paiman and coordinated by the Archaeological Institute of Afghanistan,

Fig. 1 Location of the archaeological sites of Tepe Narenj and Qol-e-tut (Kabul, Afghanistan). Aerial Photos of the sites courtesy of Z. Paiman

Tepe Narenj was the location of a Buddhist monastery that was active between the fifth and tenth centuries CE. The excavations carried out between 2004 and 2011 uncovered an architectural complex system of terraces with three levels (lower, middle, and upper) interconnected by a system of steps and platforms [11]. On the terraces in the middle portion of the site stood a series of cult chapels where the remains of multiple examples of monumental *terracruda* sculptures are preserved. The ensembles documented at Tepe Narenj consist of life-size or colossal figures placed inside chapels and linked to iconographic programmes of Buddhist cosmology (Fig. 2), some of them identified with the Tantric tradition [11].

Fig. 2 Examples of monumental terracruda sculptures preserved in the archaeological site of Tepe Narenj (Kabul, Afghanistan)

Qol-e-Tut was also a monastic complex active between the sixth-eleventh centuries CE according to archaeological research [12]. Excavations carried out between 2008 and 2013, also directed by the archaeologist Z. Paiman, and coordinated by the Archaeological Institute of Afghanistan, revealed a complex network of buildings arranged on terraces, where several chapels, two stupas, and various monastic cells were erected. The architectural remains presented mural paintings and important sculptural findings. To date, the presence of sculptures at Qol-e-tut is essentially represented by large feet preserved in situ on pedestals, highlighting a colossal polychromed Buddha in its original position erected in Chapel 13 (Fig. 3), two small figures in Chapel 15 and many sculptural fragments recovered during the excavation and preserved in the various rooms of the monastic complex.

Tepe-Narenj and Qol-e-tut are two of the best surviving examples of Afghan Buddhist archaeology, especially because of the importance of the preserved in situ monumental sculptural decoration linked to Gandharan art. These sculptures were modelled following

Fig. 3 Body and head (fallen at his feet) of the colossal Buddha of Qol-e-tut

the aforementioned method, which in these cases and roughly speaking, involved the use of a core skeleton of wood, followed by different layers of clay-based pastes, finally covered with a thin final coat of gypsum-based stucco (or in some cases a red clay layer), that exceptionally retained traces of colour.

Methodology

In order to investigate the potential presence of plants and plant parts invisible to the naked eye or to macroscopic observations, we concentrated our analysis on phytoliths. During phytoliths observation at the microscope we realised unexpectedly that fibres were also conserved so we included them in the present analysis.

Phytoliths and fibres

Phytoliths are biogenic silica particles that form in the cell lumen, in the intracellular parts between the cortex (the region proximal to the cell surface) and in the walls of plant cells [13]. Silica is one of the most abundant minerals found in the Earth's crust and enters the biogenic cycle of plants water and nutrient absorption. Most of the silica is deposited in those areas of the plant where water loss is highest, such as the flag, or uppermost leaf, and floral bracts of grasses, and leaves in trees. When the plant dies and the organic matter decays, phytoliths are left in the deposit and accumulate through time. All plant parts can theoretically deposit silica. A general pattern that has been observed is that families deposit silica in leaves often do so in other organs as well, whereas families (or species) that appear not to have phytoliths in the leaves do not have them in other organs either [13]. In woody species, the most abundant production of phytoliths occurs in the epidermis of leaves but some silicification occurs in wood and fruits and seeds. Essential for the present study are the possibilities offered by phytoliths to discriminate between grasses, and grasses subgroups, herbaceous and woody species as well as to distinguish between different plant parts (for example leaves/stem and floral parts), particularly in grasses [13].

Natural-occurring fibres can be classified in vegetal (cellulosic), animal (proteinaceous) and mineral. In the samples analysed we could observe only vegetal fibres. Vegetable fibres can be categorized according to the part of the plant the fibres come from: seed fibres (e.g. cotton), bast fibres (e.g., flax, hemp and jute), and leaf fibres (e.g., esparto grass) [14, 15]. Not much is known on preservation of loose vegetal fibres in archaeological contexts. As a rule of thumb, environmental conditions (e.g., presence and quantity of oxygen, waterlogging, desiccation, contact with fire, etc.) affect the survival of plant and animal fibre materials in various ways. In general, an acidic environment favours the preservation of proteinaceous fibres, while an alkaline environment does the same for fibres of vegetal origin [16]. However, recent studies [17] showed that fibers can undergo a silicification process which occurs first on the surface and gradually replace the inner part. Following this idea, the fibers in this study probably underwent a similar process of silicification, explaining why it was possible to recover them during the phytolith extraction process.

The hypothesis we tested with these analyses is that specific plants and parts of plants were intentionally mixed with clay-based mortars in the elaboration of the sculptures, as observed ethnographically [10] and mentioned in the literature [2–6, 8, 18–22]. In particular, we maintain that the addition of plant tissues can help not only in the drying process of clay-based plasters (avoiding cracks), but specifically in lightening the weight of modelling pastes for the elaboration of volumes (usually applied and left to dry in an upright position). In order to detect possible variations in the elaboration method of the mortars from the same context, it was considered appropriate to include some samples of walls and mural paintings in the study, since they could provide relevant comparative data depending on the architectural element. The rationale being that quantity, quality, and typology of the phytoliths and fibres encountered in the samples could be used to discriminate between the signature of plant remains occurring naturally in the clays, and plant remains intentionally added by the sculptors while preparing the different earthen mortars that shape a complete figure.

Ten fragments of *terracruda* sculptural and mural decoration were analysed: 6 from Tepe Narenj and 4 from Qol-e-tut. As some of the fragments presented distinctly different micro-layers, they were sampled applying a micro-stratigraphic approach thus resulting in a total of 13 samples analysed (Table 1).

Sampling, extraction and slide preparations

Fragments were sub-sampled in the Laboratory for Environmental Archaeology at the Universitat Pompeu Fabra (Barcelona, Spain). The fragments were scraped with a sterilised blade taking care of respecting the microstratigraphy of the sample. When the fragment was composed of a single layer, we collected first the fine fraction that had already come loose and, in case of need, we collected some more from the main piece. This was done in order to minimise the damage to the fragment. The resulting dust-like sample was collected in a test-tube, weighed and then it underwent phytolith extraction following Madella et al. [23]. This involves several steps of chemical and densimetric separation to remove carbonates, clays and organic matter and finally recover phytoliths and other botanical microremains. Resulting

Table 2 Initial weight of samples and AIF weight, total number of phytoliths, identified phytoliths, unidentified/unidentifiable phytoliths and total number of fibres present in the samples

Sample	Initial weight (g)	AIF (g)	Concentration	Total	Identified	Unidentified	Leaf/stem	Inflorescence	Woody	Concentration	Fibres
TN1	1.988	1.356	46	6	4	2	3	0	0	77	10
TN2-int	1.092	0.597	15	2	1	1	0	0	0	52	7
TN2-ext	0.575	0.352	0	0	0	0	0	0	0	121	9
TN2-nuc*	0.293	0.163	104	5	2	3	0	0	1	500	24
TN3	2.143	1.266	75	4	4	0	2	0	0	283	15
TN4*	1.659	1.129	523	81	57	24	20	8	2	161	25
TN6*	1.955	1.397	458	54	41	13	25	1	2	611	72
TN7-int*	0.158	0.018	9438	25	9	16	7	0	1	8305	22
TN7-ext*	0.267	0.149	501	15	10	5	6	0	0	667	20
QT1*	2.079	1.330	205	51	31	20	13	0	2	329	82
QT2*	1.745	1.099	399	91	73	18	43	4	8	201	46
QT3	2.177	1.345	245	49	26	23	12	6	0	140	28
QT4*	1.912	1.112	4061	304	304	0	189	60	5	868	65

Samples marked with * will be discussed below as their phytoliths or fibres values are above the average for their group residues were mounted on microscopy slides with a permanent mounting medium.

Microscopy observation and identifications

Slides were observed under transmitted light microscopy (Euromex iScope) at magnifications of 20X and 40X. The entire slide was scanned and all phytoliths and fibres counted and photographed. Identification of phytoliths followed published reference materials (mainly, Piperno 2006 [13] but also the UPF's own reference collection) whereas the identification of fibres was performed observing the morphological characteristics of the longitudinal sections to visualise the general appearance of the fibre and its possible changes, the nodes, the possible dislocations, the cracks and the cross markings and their orientation with respect to the longitudinal axis of the fibre as well as the presence of lumen [24–27]. Phytolith and fibres concentration was calculated per gram of the Acid Insoluble Fraction (AIF), which is the weighted residue after all the chemicals have been applied and before densimetric separation. Phytolith nomenclature follows ICPN 1.0 [28].

Results

Phytoliths

Phytoliths are present in all but one sample (TN2-ext), in generally low quantities and with different degrees of preservation. Table 2 shows the summary of results.

Concentration

As the whole slide was scanned, phytolith concentration was calculated according to the following formula:

$$conc = (N * (P/p))/AIF$$

where: N = total number of phytolith counted.P = total silicates extracted (g).p = silicates on slide (g).AIF = Acid Insoluble Fraction (g).

Concentration is quite low in almost all samples, and it is skewed by only one sample at each site (TN7-int and QT4). Interestingly, the sample that presents the highest concentration is TN7-int (Fig. 4), which is more than double that of the highest sample from Qol-e-tut. This pushes the average of TN higher than QT (1240 for TN and 1227 for QT) whereas all other indicators are higher in Qol-e-tut (Fig. 5).

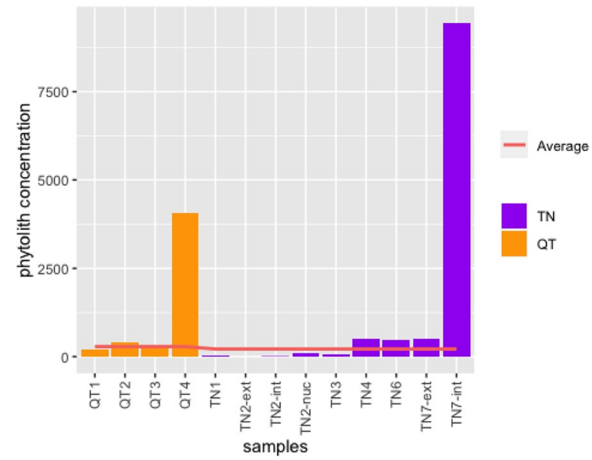


Fig. 4 General comparison (averages) between samples from Qol-e-tut (QT) and Tepe Narenj (TN)

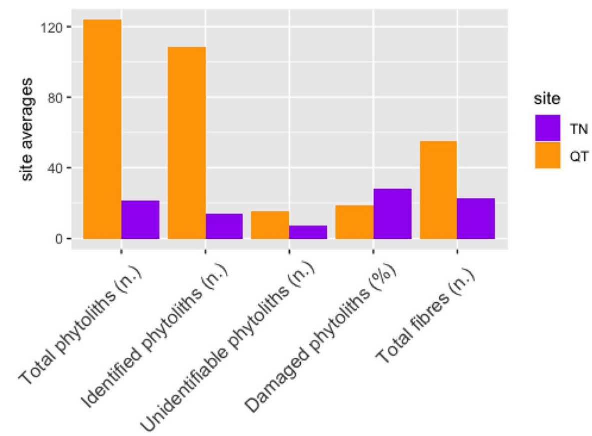


Fig. 5 Phytolith concentration. The average is calculated per site, excluding samples QT4 and TN7-int

Preservation

Preservation is generally quite bad, phytoliths show signs of taphonomic damage, especially chemical dissolution (Fig. 6). The percentage of taphonomised phytoliths is higher in Tepe Narenj (28%) than Qol-e-tut (19%) (Fig. 5). This value is particularly high in sample TN2-ext (100%) and TN2-nucleus and TN3 (50%). However, this is not significant as the total number of phytoliths in these samples is extremely low (n. < 5). At Qol-e-tut there seems to be a direct correlation between the concentration and the number of morphotypes identified in the samples (0.75, Fig. 7) pointing to generally poor preservation [29]. Conversely, this correlation is low for samples from Tepe Narenj (0.12).

Morphotypes

The general composition of phytolith assemblages identified in samples from Tepe Narenj and Qol-e-tut is very similar, dominated by leaf/stem morphotypes (elongate psilate and bulliforms) which represent in both cases over 75% (Fig. 8). At Tepe Narenj there is a slightly lower presence of inflorescence (elongate echinates, dendritics and elongate wavy) morphotypes and a slightly higher percentages of woody indicators (blocky, globular rugose and scalloped) than at Qol-e-tut.

Both inflorescences and short cell morphotypes point to a dominance of C3 grasses, that is grasses adapted to wet or dry cool environments. In all the samples only < 10 phytoliths can be attributed to C4 grasses, plants that are more adapted to warm environments. Silica skeletons, phytoliths in anatomical connection that represent parts of plant tissues, are practically absent, the only one identified being transport tissue (vessels). This makes identification even to genus level impossible.

Fibres

The identification of archaeological fibres is somehow hindered by the lack of appropriate reference material as most of the reference collections tend to concentrate on modern (post industrial revolution) fibres [14]. As a general rule 4 big categories of patterning can be observed under the microscope and used for a first qualitative identification [30]:

1. Fibres with scaling: animal hairs (all of the keratin fibres except silk are included in this group)
2. Fibres with cross-markings: vegetable fibres (other than cotton)
3. Convoluted fibres: cotton and tussah silk
4. Other fibres: all the man-made fibres, bombyx silk and asbestos

Despite the fact that the extraction protocol used was not specifically directed at fibres recovery and identification, we considered that silicification of fibres could allow their quantification in the same way as phytoliths.

All the samples studied show high to very high fibre numbers, which was unexpected as they were not macroscopically detected or discriminated by previous X-ray Micro-Computed Tomography (TAC) analysis [1]. Fibre concentration has been calculated on the AIF, in an equivalent way to phytolith concentration, substituting total number of phytolith counted with total number of fibres. Similarly to phytoliths, the 2 samples with highest concentrations are TN7-int and QT4 (Fig. 9). In this case, however, samples TN7-int has 10 times more fibres than QT4.

Types

As noted above, none of the fibres observed during this study present the scalar pattern attributable to animal hair. Therefore the fibres present in the samples should be either vegetal or mineral, although Carr and colleagues [26] note that archaeological animal hair might lose its scaling pattern. However, it would be improbable that all the fibres observed have undergone such deterioration, and if animal hair were present, at least some of the fibres would present the scale pattern.

The large number of preserved fibres (503 in total—see Table 2) in the samples from Tepe Narenj and Qol-etut is remarkable if we take into account the small amount of sample taken and the fact that fibres very rarely preserve in archaeological samples. A first identification, based solely on visual observation under transmitted light microscope of the mounted slides prepared for phytoliths study, seems to clearly point out the dominant presence of bast fibres. The term bast is commonly used to describe bundles of tightly joint fibre cells found in the stem of plants like hemp (*Cannabis* sp.), flax *(Linus usitatissimum* L.), jute (*Corchorus* sp.), ramie (*Boehmeria nivea* (L.) Gaudich.) and nettle (*Urtica dioica* L.) or in the inner bark of wood. Bast fibres have similar general morphological characteristics that allow them to be recognized relatively easily. Each bast fibre cell consists of a cell wall, which surrounds an empty space (lumen); the length of the fibre cells and wall thickness vary largely among species. However, some anatomical characteristics can be redundant (i.e., different species can present the same characteristic for some of the identification criteria). Therefore, the correct identification of fibres that allow distinguishing between species must rely on the observation of a high number of samples.

Based on the observation of the lumen and cell wall morphological characteristics of the fibres detected in the sculpture fragments of Tepe Narenj and Qol-e-tut, these have been tentatively identified as bast fibres belonging to the nettle / ramie family (see Figs. 10 and 11).

The identification of fibres is not trivial, thus these notes have to be taken with caution. Numerous authors have previously reported the difficulties of correctly identifying the different species of the so-called bast fibres and the interest of using different complementary techniques to make an accurate identification [31–33]. Likewise, in recent years, errors that have occurred in the identification of textiles, especially from archaeological excavations, have been brought to light, generally assimilating remains of fabrics made from bast fibres to flax fibres [34, 35]. In accordance with this interest in improving identification techniques and expanding the knowledge of plant fibres used in antiquity, the presence of European nettle has been detected in numerous archaeological remains from northern Europe documenting the use of wild (uncultivated) plants to obtain textile fibres [36]. Either European Nettle (*Urtica dioica* L.) or Himalayan Nettle (*Girardinia diversifolia* (Link) *Friis*) are herbaceous perennial and flowering plants and are widespread species in Europe, Asia and America that are adapted

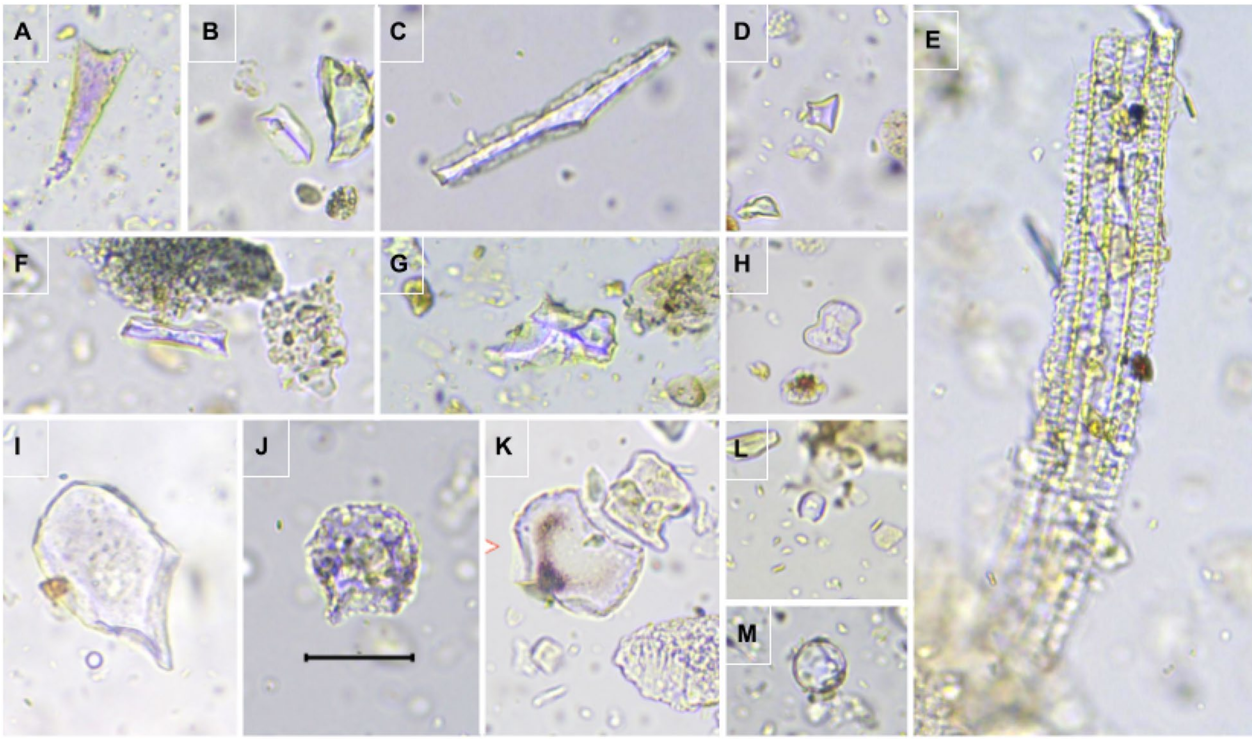


Fig. 6 Microphotographs of phytoliths identified in the samples. **A** acicular hair; **B** short trapeziform; **C** scalloped form woody dicotyledon; **D** rondel; **E** transport tissue silica skeleton; **F** elongate trapeziform; **G** scalloped; **H** bilobate; **I**–**K** bulliforms showing good preservation conditions (**I**), chemical dissolution **J** and mechanical breaking **K** due to taphonomic processes; **L** saddle; (M) globular. Scale bar 50 μm (applies to all microphotographs)

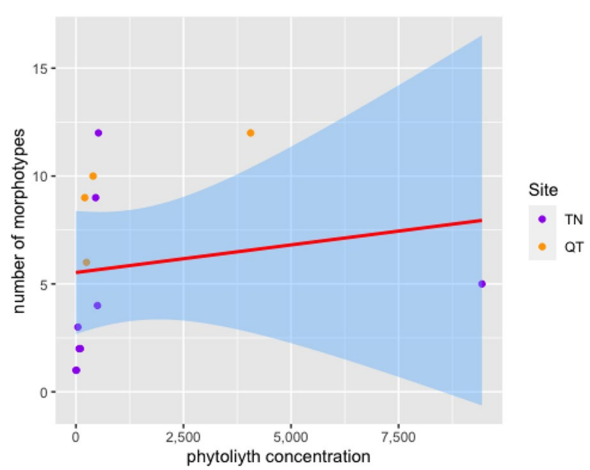


Fig. 7 Correlation between phytolith concentration (x-axis) and number of morphotypes identified (y-axes)

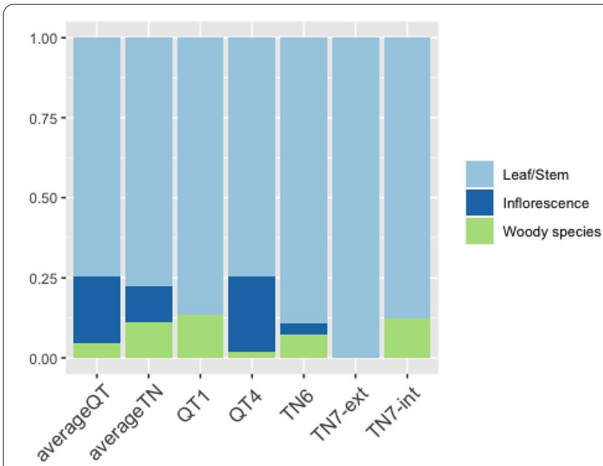


Fig. 8 Proportion of leaf/stem, inflorescence and woody species morphotypes identified. The average composition of site assemblages is presented alongside the composition of samples considered for discussion

to different climatic conditions, and its fibres have been used in rope making, netting, weaving and also in paper production [37].

Ramie is a member of the Urticaceae or Nettle family. This fact explains why nettle and ramie fibres show very similar morphological patterns, which makes it difficult to distinguish between the two species. The outer shape of these bast fibres, unlike what usually happens in flax

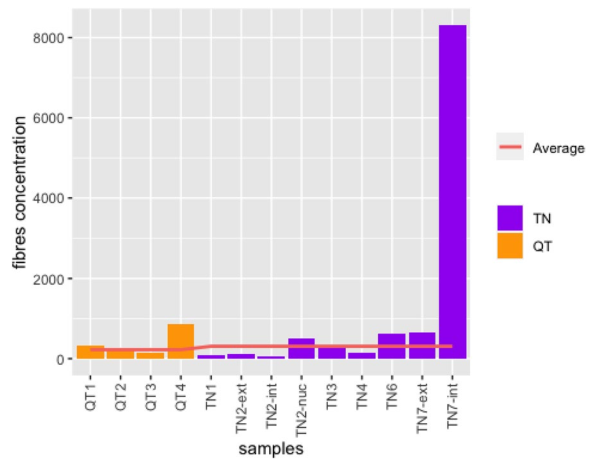


Fig. 9 Fibres concentration. The average is calculated per site, excluding samples QT4 and TN7-int

and hemp, varies, and some show a cylindrical shape in their longitudinal section and others are wider and flattened, like a ribbon, and may present some twists. Regarding the surface, fibres of ramie / nettle present deep fissures and striations that are oriented mainly diagonally with respect to the axis of the fibre and are visible in the cell wall. This cell wall, thick in relation to that of other bast fibres, can vary in thickness throughout the fibre, showing considerable thickening in some parts. Likewise, the lumen of ramie / nettle fibres presents variations in shape and width, but in general it is always larger than the lumen of the other bast fibres. Considering this description we can say that the ramie/nettle fibres have an irregular shape, besides being the longest among the bast fibres [24, 38–40].

However, a large part of the fibres from Tepe Narenj and Qol-e-tut samples cannot be clearly identified by their morphological characteristics alone, something that is probably not helped by the sample preparation carried out according to phytolith extraction parameters. Nevertheless, it should be noted that curiously ramie fibres are stable in alkaline media [41, 42] and not harmed by mild acids [41].

Preliminary interpretation

To understand possible paths of inclusion of plant materials into the clays used for modelling terracruda sculptures textual evidence [2–6, 8, 18–22] and ethnographic observations [10] were taken into consideration. The ethnography indicates that the clay is purified before being used to produce the sculptures. This purification involves the careful elimination of all macroscopic impurities (including macroscopic plant remains) through the use of water (decanting, washing and sieving). Although it is reasonable to think that the preparation of clays before sculpting (e.g., decanting in water, sieving, etc.) should have eliminated any possible plant material originally present in the raw clays, we opted to maintain a conservative approach and consider samples whose values below the average of their group, as possible natural contamination. Therefore, here we only discuss those samples that present concentrations of phytoliths or fibres above the average for their group (TN or QT, excluding from the calculation of the average TN7-int and QT4). These samples are highlighted in Table 2.

Significant samples can be divided in 3 groups: (1) fragments enriched in phytoliths, (2) fragments enriched in fibres, and (3) fragments enriched in both phytoliths and fibres.

1. Samples enriched in phytoliths: TN4 and QT2 [clothing fragments]—these two samples present the highest variability of phytoliths morphotypes (12 and 10 different morphotypes). In terms of general composition, they are quite dissimilar and also different from the average groups' composition. Sample TN4 is much more enriched in chaff phytoliths than both

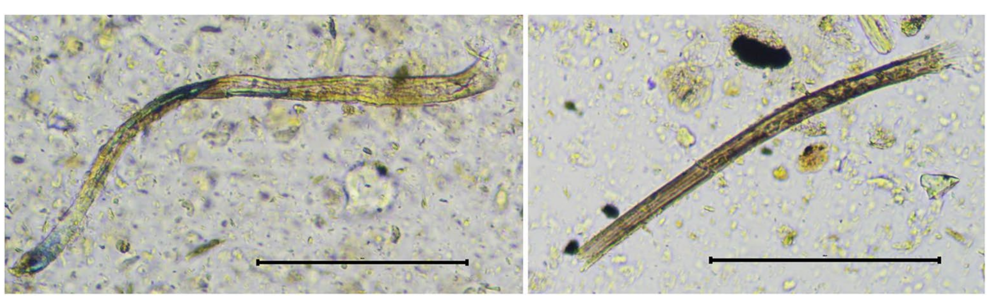


Fig. 10 Two examples of the nettle/ramie fibres from QT samples clearly identified according to morphological criteria (scale bar = 100 µm). Left: Change in shape and width with slight twist. Right: Fragment of fibre with a flattened ribbon shape with some transversal marks and vertical striations

Fig. 11 Some of the nettle/ramie fibres from TN samples clearly identified according to morphological criteria (scale bar = 100 µm). Top left: change in the external shape of the fibre, slight twists and numerous diagonal striations characteristic of nettle/ramie. Top right: diagonal striations as well as thickened cell walls and visible lumen. Angular twisting, common in ramie/nettle fibres. Bottom: long fibre with slight twists and changes in cell wall thickness (in these cases the appearance of the nettle/ramie fibres can be slightly similar to cotton fibres)

QT2 and the average of TN samples. QT2 presents a higher component of wood phytoliths than both TN4 and the average of QT samples (Fig. 4).

Chaff phytoliths from TN4 are mainly represented by elongate echinates, which are characteristic of C3 grasses. This subgroup of grasses is well adapted to cold and humid environments and includes, amongst many other species, some of the most common cereals such as wheat, barley, oats and rice. Unfortunately, due to the low number of phytoliths and the absence of silica skeletons or any other diagnostic morphotypes, it is not possible to identify which species produced them. The wood phytoliths from QT2 are represented both by morphotypes produced in dicotyledon leaves as well as form the lignified part of the plant. Again, it is not possible to identify which plant produced them to the genus or species level, but they might indicate the presence of small pieces of wood intentionally added.

2. Samples enriched in fibres: TN2-nucleus and QT1 [niche and mural painting fragments]

According to their morphological characteristics, the fibres that have been identified in TN2 (25) and QT1 (81) corroborate the use of nettle/ramie. In TN2-nucleus: 7 show clear characteristics that identify them with nettle/ramie (Fig. 12), 6 are compatible and 12 are not identifiable. In QT1: 51 show clear characteristics identifiable with nettle/ramie, 12 appear compatible and 19 are not identifiable.

To date hemp and other fibres have been identified in Indian historical mural plasters [43–45], and jute has been observed ethnographically in the process of making a clay idol to make the ropes placed around the bamboo and straw skeleton, and also mixed with clay-based mortars when these require an extra strength, as in the case of finger modelling [10]. For historical sculptures, other works mention the presence of silk [6], cotton [6, 46], hemp [6, 46] or the generic "fibres" in the clay-based mortars of Chinese [46] or Himalayan

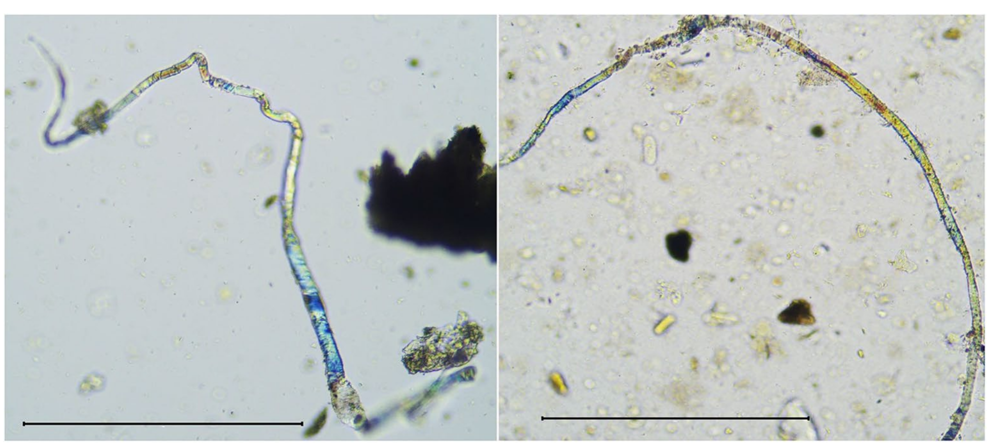


Fig. 12 Fibres from TN2-nucleus (left) and QT1 (right) showing characteristics of nettle/ramie family (scale bar = 100 µm)

[4] monumental terracruda sculptures, without providing scientific diagnostic data to accompany such statements. The exception is the study of the fibres added to the modelling pastes of the Bamiyan Buddhas (Afghanistan), where the addition of hair from different animals was scientifically identified [47].

Ramie (Boehmeria nivea (L.) Gaudich.) is a flowering plant of the Urticaceae family originating from eastern Asia e. The genus Boehmeria comprises about 100 species, with B. nivea being the most widespread. It is an enduring plant, which grows to maturity in 44–55 days in a hot and moist climate. Ramie fibres are found on the bark layer of the stem. This fibre consists of 73%–75% cellulose, 12%–14% hemicellulose, 8%–10% pectin and 1%–1.5% lignin [48]. The fibres coming from the stem of ramie are one of the oldest textile fibres, documented since prehistoric times in China, India and Indonesia, and mentioned and praised in Sanskrit poems [49], but, as far as we know, never before identified in Afghan archaeology, nor mentioned in connection with examples of Silk Roads archaeological terracruda sculpture.

3. Samples enriched in both phytoliths and fibres: TN6, TN7-int, TN7-ext and QT4 [wall (in contact with the back side of the sculptures), finger and toe fragments]

Although the absolute number of phytoliths identified in TN6, TN7-int and TN7-ext is extremely low, when concentration was calculated it showed that it was significantly higher than the average of all other samples. TN6 and TN7-ext present values of phytolith concentration more than double that of their group and TN7-int 43 times higher. Unfortunately, the low absolute number does not allow to make any more inference beyond the fact that this enrichment seems intentional. For TN7 (both int and ext) this is in total concordance with the mineralogical and TAC studies [1]. As for sample QT4 the absolute number of phytolith is the highest of all samples and, by discipline convention usually applied to analyses of soils, the only one that allows quantifiable interpretation (n > 300). The general composition of these samples is almost identical to that of its group, with over 74% of straw and 23% of chaff indicators. Woody morphotypes are roughly half the average for the group (Fig. 8). Again, the chaff component can be reconducted to C3 plants but no further taxonomic identification is possible.

The fibres identified in these samples are, again, mainly bast fibres, with features largely compatible to the nettle/ramie family (Fig. 13). It is notable that in the case of TN7, previous TAC analyses were able to identify 3 types of components (clay, aggregates and voids associated with decomposed straw), without distinguishing the remarkable presence of preserved fibres at the microscopic level [1].

Fig. 13 Fibre 4 from TN7-int showing diagonal striations characteristics of nettle/ramie family (Scale bar = 100 μm)

Knowing the precise composition of clay-based mortars is a crucial aspect to understand the manufacturing process of earthen heritage and a necessary information to replicate in any conservative intervention aimed at performing suitable consolidation grouts with correct physical–mechanical properties. In this sense, for monumental *terracruda* sculptures, distinguish between straw and fibres, identify the species associated, precise their ratio, verify their preservation or not, and understand their role and behaviour, are data of crucial importance as knowing the type of clays and aggregates and their proportions, and as these, must be one more element to consider when designing any curative or restorative treatment.

As we know from ethnographic observations, it is their precise use according to the elaboration process of the entire sculpture and the behaviour of both additives (straw/husk and fibres) in the mixture of clay-based mortars that technically allows the elaboration of large and colossal examples. Nowadays in Bengal, only rice husk is mixed in the inner earthen mortars where more adherence is needed to fix these layers to the internal skeleton; mixed rice straw and husk are added to the intermediate layers to give volume to large sculptures; and only jute fibres in the final layers or in parts of the sculpture that need an extra rigidity or stability [10].

In the case of the TN and QT sculptures, the analyses of phytoliths and fibres point also to the use of straw and fibres in different ways depending on the architectural elements to be manufactured. Thus, the mural samples associated to surface finishes (TN2-int and QT1) show a rather high enrichment in fibres, sculptural draperies

(TN4 and QT2) stand out in phytoliths, and fragments in contact with or forming internal parts of the sculptures (TN6, TN7 and QT4) highlight for their high enrichment in both, phytoliths and fibres.

This seems to agree with the idea that the modelling of elements where volume is necessary (draperies, fingers, etc.) to reduce the weight of the modelling pastes, requires more straw and husks (with more presence of phytoliths) whereas the fragments associated to mural surface finishes (internal part of a niche and mural painting) show a prevalence of fibres only. The high presence of fibres in almost all samples would also indicate that this type of additive was relevant in the preparation of all earthen mortars to favouring their correct drying and, in the case of sculptures, highlighting when extra rigidity or firmness was need (as is the case of TN and QT finger and toe). This is corroborated by ethnographic observations carried out in West Bengal, where the artists of clay (the *kumors*) mix frayed jute fibres especially in the modelling of fingers, headbands or elements that require a certain degree of stability.

Additionally, if we take into account that some of the mentioned plants are being studied today for their good physical–mechanical behaviour as green substitutes for synthetic additives in cements or resins, their study becomes even more relevant. This would be the case of rice husk and ramie fibres, both also mentioned as mixed in the inner clay-based mortars of Japanese *terracruda* sculptures of the Nara period, eighth century [50]. Rice husk is a highly produced waste that is difficult to recycle, since its characteristics make it unusable for food exploitation (it can cause death in humans and animals if ingested regularly), nor for easy degradation/recycling. This is due to its high silica content, which on the contrary makes rice bran extremely useful for construction, being a material that does not absorb moisture, in addition to being fireproof and lightweight [51]. It seems interesting also to note that the current name given in West Bengal to clay mortar mixed with rice husk is "*tus-mati*" or "*atha-mati*", which could be translated as "bran earth" or "adhesive earth" respectively. A name that suggests the possibility that the addition of husks in the elaboration of clay mortars gives them bonding and strength qualities, something also pointed out in recent studies carried out in historical Indian mortars [44]. These characteristics (very interesting in the production of new, more environmentally friendly construction materials) can also be of relevance for curative or restorative interventions, as they could facilitate the design of compatible clay-based mortars, especially in its micronized variant, reducing the weight of consolidation/reintegration grouts while giving them needed properties according to conservation criteria. In turn, ramie fibres have been proven to provide excellent performance when compared to the other vegetal fibres, while being highlighted also for their valuable mechanical properties [52]. Ramie is between the bast fibres categorised as having more tensile strength, durability and flexibility [49] features that are being studied to replace fiberglass in industrial applications. Moreover, ramie is resistant to insect attacks, light, rotting, alkalis, mildew, and bacteria [53].

Conclusions

The phytolith and fibres analyses carried out on the mural and sculptural fragments from Tepe Narenj and Qol-e-tut seem to indicate that most of the samples studied present an intentional addition of herbaceous materials that differs depending on the type of artwork to be produced. The species and parts of plants used according to the geographical area/environment or the size of sculptures, probably plays in favour or against a better preservation of the sculptures and it is also a relevant information to enlarge the knowledge about the creative method and its diffusion, giving precious data about its transmission and its adaptation to the different Asian regions where this spiritual and technical tradition of representing the divine figure in raw earth arrived along the Silk Roads. In this respect, the identification of silicified bast fibres in the TN and QT samples, whose characteristics seem to indicate that they are largely from the nettle/ramie family, is an information of particular significance. As far as we know, ramie/nettle has never been identified before in Afghan archaeology, nor scientifically identified in connection with examples of Silk Roads monumental *terracruda* sculpture.

It is fundamental for both conservation and historical studies, to correctly understand the use of plants and fibres in the elaboration of monumental *terracruda* sculpture. Therefore, it is recommended to conduct microscopic examinations whenever working on this type of artifacts. As we evidenced in our work, and considering their importance, it is advisable to adopt an analytical procedure specific for fibre extraction and identification, in order to make sure to recover them undamaged and unbiased. However, in the case of silicification of fibres, the method used for the extraction of phytoliths has proven to be a valid preliminary study approach for their detection and quantification.

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Author contributions

ML-P and CL conceptualised the research, wrote the main manuscript text and prepared figures. CL performed phytolith and fibre extractions and phytolith analysis GC-F conducted fibre analysis and identification, NAN gave access to the sites and supervised archaeological study of the samples. SRB coordinated the ethnographical comparative study BC, JS-C and DM supervised ML-P PhD. All authors reviewed the manuscript and contributed to the final draft. All authors read and approved the final manuscript.

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Availability of data and materials

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Declarations

Competing interests

The authors declare no competing interests.

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