Veget Hist Archaeobot (2015) 24:121–133
DOI 10.1007/s00334-014-0486-7

ORIGINAL ARTICLE

A tale of multi-proxies: integrating macro- and microbotanical remains to understand subsistence strategies

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Received: 31 December 2013 / Accepted: 30 August 2014 / Published online: 16 September 2014

Abstract The integrated analysis of several proxies in order to answer a research question is a widespread approach in palaeoecology, but it is not well developed in archaeobotanical research. Applying a multi-proxy approach to archaeobotany has several advantages: a more diverse anatomical and taxonomical representation of the original plant input and a better understanding of taphonomic processes, both depositional and post-depositional. The aim of this paper is to show how a multi-proxy approach can enrich our understanding of plant-related subsistence strategies. Macro and microbotanical analyses were carried out on samples from Shikarpur, a Chalcolithic settlement in Kachchh, Gujarat, northwest India. This settlement is located in a semi-arid region with wet/dry cycles and highly saline soils that influence the preservation of charred remains, so that they do not offer the full picture of plant-related subsistence strategies. We show that the combination of different proxies is crucial to cross-validate the results and to gain a wider understanding of plant use strategies. The inhabitants of Shikarpur relied on a double-cropping system based on local small millets and pulses, and they also consumed cereals, tubers and sedges.

Keywords Multi-proxy · Phytoliths · Starch grains · Macrobotanical remains · Archaeobotany · Indus valley

Introduction

Plants used and transformed by people can produce a diverse record that can be considered as a proxy of their choices and activities, and in certain cases of ecological conditions too. In a broad sense, the term 'proxy' is used to define a representative or intermediary. In palaeoclimatology, a proxy is defined as "a local record that is interpreted using physical or biophysical principles to represent some combination of climate-related variations back in time" (Folland et al. 2001, p. 130). Noise and possible biases make it necessary to calibrate and cross-validate proxies in order to obtain more accurate and reliable palaeoclimatic reconstructions. A multi-proxy approach is also commonly adopted in palaeoecological studies, particularly in palaeolimnology (Birks and Birks 2006 and references therein). In palaeoecology, a proxy is understood as a record of changes that can be measured or analysed to reconstruct past ecosystems and biotic responses to natural or human-caused changes (Birks and Birks 2006). Palaeoecological proxies include fossil organisms such as diatoms, phytoliths and pollen grains, as well as sediment characteristics which are measured through physico-chemical analyses.

Despite the fact that archaeobotany shares several methodological approaches with palaeoecology, the

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Communicated by F. Bittmann.

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concept of proxy is not much theorised and, in general, the major evidence (proxy) is considered to be the charred remains record. This is due to (a) visibility, because charred remains can be seen by naked eye, (b) relatively easy methods of recovery either handpicked or by flotation, and (c) direct analysis without previous chemical processing.

An example of the single-proxy approach in archaeobotany, based on charred remains, is the study of plant-related subsistence strategies and agricultural practices. However, as a single-proxy approach, plant microremains offer a valuable alternative. Phytolith and starch grain analyses have made major contributions to the understanding of plant domestication processes worldwide (e.g. Piperno et al. 2009). Moreover, direct evidence of past human diet has been gained from plant microremains recovered from human dental calculus (Henry and Piperno 2008) or artefacts involved in food processing such as grinding stones (Piperno et al. 2004). Similarly to plant macroremains, phytoliths and starch grains have also been used to establish the practice of irrigated agriculture (Madella et al. 2009; Rosen and Weiner 1994), dry farming (Lu et al. 2009) and vegeculture (Barton and Denham 2011), as well as to study crop-processing activities (Harvey and Fuller 2005; Yang et al. 2013).

Although macro and microremains can be recovered from the same contexts, only a few studies have actively pursued an integration of data from both lines of evidence (Delhon et al. 2008; Dickau et al. 2012). The integrated analysis of charred macroremains, phytoliths and starch grains can widen the information spectrum at several levels:

Taxonomy

The combined use of macro- and microbotanical remains increases the number of taxa identified, independently of the preservation pathways. Microremains allow for the recognition of taxa from leaves (Out and Madella in press; Yang et al. 2013), roots and tubers (e.g. Chandler-Ezell et al. 2006) and fruits such as banana (Denham et al. 2003 for starch and Mindzie et al. 2001 for phytoliths). Charred seeds and related floral parts, on the other hand, are often strongly taxonomically diagnostic. For example, charred small millets can usually be identified to species level, whereas starch grains are, at best, diagnostic to genus level (Krishna Kumari and Thayumanaban 1998; Liu et al. 2011; Yang et al. 2012). The potential of phytoliths to differentiate between small millets has only started to be evaluated outside the two main genera, *Panicum* and *Setaria* (Madella et al. 2013 and references therein).

Anatomy

A multi-proxy approach allows for the identification of different plant parts, useful for both dietary and non-dietary investigation of plant use (Fig. 1). Plant parts seldom preserved in the macrobotanical record such as chaff of small grasses, leaves or culms can be identified from plant microremains (Lu et al. 2009; Madella et al. 2013; Out and Madella in press; Yang et al. 2013; Zhang et al. 2011).

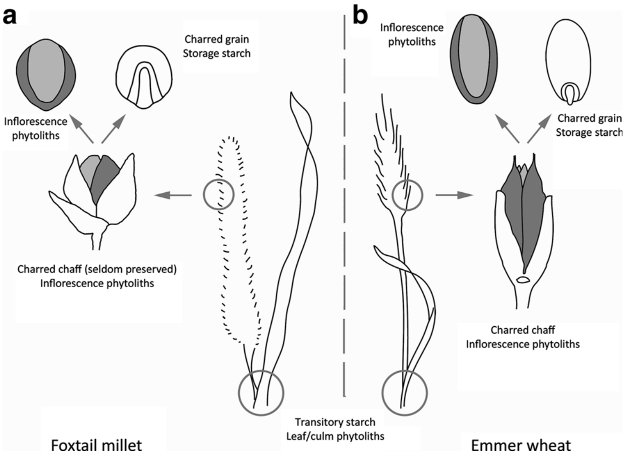


Fig. 1 Idealised drawings and examples of proxies (macro and microbotanical remains produced by different plant parts) from **a** *Setaria italica* (L.) P. Beauv. (foxtail millet), and **b** *Triticum turgidum* ssp. *dicoccon* (Schrank) Thell. (emmer wheat)

Taphonomy

Plants and plant parts are preferentially preserved depending on their intrinsic characteristics (soft vs. hard tissues), processing technique (roasting, boiling, etc.) and post-depositional settings (dry vs. wet environments, bioturbation, etc.). A multi-proxy approach offers the possibility to analyse a wider spectrum of plant residues, therefore allowing more precise evaluations of the original assemblages. Phytoliths are usually preserved regardless of the depositional conditions, since they are not dependent on fire for preservation as most macroremains are. Starch grains can be easily degraded by enzymes, bacteria and other organisms of the soil (Haslam 2004). However, when trapped in dental calculus or pores in artefacts they can be preserved for thousands of years in diverse environmental settings (Torrence 2006, Table 1). Starch taphonomy and preservation has been experimentally assessed in a set of tests by Lu (2003; in Haslam 2004).

To summarise, a multi-proxy approach offers the possibility of wider anatomical and taxonomical identification as well as overcoming some taphonomic effects, resulting in a more representative set of data from the original input. The aim of this paper is to illustrate how the analysis of multiple archaeobotanical proxies from the same archaeological contexts improves and enriches our understanding of plant use. The case study is from the Chalcolithic Harappan settlement of Shikarpur (ca. 2500–1500 BC), located

Table 1 Fire-related contexts analysed in this study. Phytoliths are expressed in concentration per g of AIF (Acid Insoluble Fraction). Starch grains are expressed in concentration per g of original sediment

ID	Description	Sediment vol. (l)	Phytoliths	Starch grains
Ash 1	Area with ash	20	5,611,441	7
Ash 2	Area with ash	40	4,396,082	12
Ash 3	Area with ash	20	117,241	5
Pit 1	Pit	60	10,822,431	20
Pit 2	Pit	20	8,518,178	5
BA 1	Area with burning activity	20	1,199,512	7
BA 2	Area with burning activity	10	7,191,799	10
Hearth 1	Fireplace	30	608,497	15
Hearth 2a	Fireplace, upper level (ashy)	20	792,819	15
Hearth 2b	Fireplace, lower level (compact)		274,166	13
Oven	Small oven delimited by brick, stone and clay plaster		3,880,028	5

in Kachchh, Gujarat, northwest India, at the fringe of the Indus valley. The paper discusses the evidence from integrated macro and microbotanical analyses from fire-related contexts and grinding stones.

Archaeobotanical background

Harappan subsistence strategies varied between the core area in the main Indus valley and the peripheries. In the Indus valley, subsistence relied on winter crops (*rabi*) such as *Triticum* spp. (wheat), *Hordeum vulgare* L. (barley), *Cicer arietinum* L. (chickpea), *Lens culinaris* Medik. (lentil) and *Pisum sativum* L. (pea). In the southern peripheral areas such as Gujarat, crops were mainly cultivated in summer (*kharif*), including large and small millets, *Oryza* sp. (rice) and tropical pulses such as *Vigna radiata* (L.) R. Wilczek (mung bean), *Vigna mungo* (L.) Hepper (black gram) and *Cajanus cajan* (L.) Huth (pigeon pea) (Fuller and Madella 2001).

Previous studies of plant-related subsistence strategies in Harappan Gujarat focused mostly on charred macroremains. Archaeobotanical research at Kanmer, a settlement in Kachchh occupied from the Early to the Post Urban Harappan Period (Pokharia et al. 2011), shows a switch from a predominance of winter crops, mainly barley, in the earlier phases towards a more diversified strategy at the end of the Harappan occupation, when the assemblage is dominated by summer crops. Plant remains from Rojdi, located in the Saurashtra peninsula in Gujarat, show the predominance of summer crops (millets and pulses) during both the Urban and Post Urban phases of occupation. Post Urban Harappan, 2nd millennium BC Oriyo Timbo has a plant assemblage dominated by summer crops, especially millets such as *Eleusine coracana* Gaertn. (finger millet), *Setaria* and *Panicum* spp. and to a minor extent, pulses (*V. mungo*) (Reddy 1997). In contemporary Babar Kot the crop assemblage additionally included winter pulses, such as *L. culinaris* or *Vicia* sp. (Reddy 1997).

Macrobotanical analyses from previous field seasons at Shikarpur by Chanchala and Saraswat show the presence of *Triticum aestivum* L. (bread wheat) and *Eleusine coracana* and *Setaria* sp. (small millets) (IAR 1995, 2002). However, Fuller (2003, 2006) questioned the presence of African crops such as *E. coracana* at Shikarpur and other Harappan settlements during the 3rd millennium BC. The author also pointed out the possible confusion between *Setaria* sp. and *Brachiaria ramosa* (L.) Stapf (browntop millet). Therefore, the identification of *E. coracana* and *Setaria* sp. at this settlement cannot be taken as conclusive.

Materials and methods

Shikarpur (N 23°14′15″, E 70°40′39″) is located in Kachchh, a semi-arid region with an average annual rainfall of ca. 400 mm, most of which falls during the monsoon period between June and September. The materials analysed for this study were collected during the 2012 field season, when the eastern part of the fortified area was excavated to expose the structures of occupational Phase II, Late Urban Harappan, ca. 2200–1900 BC (Bahn and Ajithprasad 2008).

A total of 923 l of sediment were floated of which 240 l from nine fire-related contexts such as hearths, ashy patches or areas with burning activity were analysed for this study. For each context, the sampling strategy consisted on collecting a minimum of 10 l of sediment for flotation and a 5 × 3 cm zip-lock bag of sediment for microremains extraction. Bucket flotation was carried out with a 0.25 mm mesh. It was not possible to collect a flotation sample from one oven due to a mishap during the excavation. A total of 11 phytolith and starch grain samples were analysed (Table 1).

Furthermore, 20 microremain samples were analysed from 18 grinding tools (Table 2). Quern 7 presented two used surfaces (a and b) which were sampled and analysed separately. Quern 9 was broken into two fragments (a and b), which were also separately sampled and analysed. In addition, 11 control samples from the same contexts of the grinding tools were checked to assess them for contamination, which was preliminarily appraised by checking differences in microremains concentration, where higher

Table 2 Grinding stones analysed in this study. Descriptive terms after Wright (1992). Phytoliths are expressed in concentration per g of AIF (Acid Insoluble Fraction). Starch grains are expressed in concentration per g of original sediment

ID	Description	Grinding stone		Control sample	
		Phytoliths	Starch grains	Phytoliths	Starch grains
Quern 1	Quern fragment	4,634,268	275	1,530,812	15
Quern 2	Saddle-shaped quern	4,182,827	156	1,199,512	138
Quern 3	Half saddle-shaped quern	3,090,134	1,940	725,916	12
Quern 4	Half saddle-shaped quern	1,683,901	201	1,530,812	15
Quern 5	Saddle-shaped quern	4,400,743	2,048	1,428,320	2
Quern 6	Half saddle-shaped quern	1,896,012	281	433,430	7
Quern 7a	Half saddle-shaped quern, face a	3,136,372	660	433,430	7
Quern 7b	Half saddle-shaped quern, face b	2,138,836	213	433,430	7
Quern 8	Saddle-shaped quern	4,511,346	368	1,530,812	15
Quern 9a	Basin grinding slab, fragment a	4,149,532	369	1,530,812	15
Quern 9b	Basin grinding slab, fragment b	1,912,030	1,571	1,530,812	15
Hand 1	Spherical handstone	3,596,088	591	1,820,230	15
Hand 2	Oval, irregular handstone	1,066,864	506	837,048	71
Hand 3	Bifacial, rectilinear handstone	23,493	411	282,607	25
Hand 4	Spherical handstone	2,191,360	263	607,404	5
Hand 5	Spherical handstone	2,052,040	1,206	649,305	0
Hand 6	Bifacial, rectilinear handstone	1,211,538	540	433,430	7
Hand 7	Bifacial, rectilinear handstone	1,224,839	148	433,430	7
Mortar	Boulder mortar	2,161,381	156	1,062,273	140
Pestle	Bipolar cylindrical pestle	12,316,703	1,206	1,530,812	15

concentrations were assumed for stone tools; further experiments on this issue are ongoing. Residue recovery consisted of a two-step process in which the outer layer of sediment was first dry brushed from the used surface(s) of the grinding stone (dry sample), and then the inner layer of sediment was brushed with deionised water (wet sample) (Hart 2011). Microbotanical remains were extracted from the wet sample with a combination of the methods described in Madella et al. (1998) and Horrocks (2005), adapted for small samples recovered from grinding stones (generally < 1 g). Loose sediments from fire-related contexts and control samples were processed using the same extraction protocol to allow for comparison. Phytoliths, both single cells and silica skeletons, and starch grains were observed at 200 and 630 magnifications with a Leica DM 2500 microscope equipped with a Leica DF 470 camera. Macroremains were identified using a Leica EZ4 D stereoscope. Taxonomical identification of all plant remains relied on the plant reference collection of the BioGeoPal Laboratory (CaSEs, Barcelona) and on relevant literature (Fuller and Harvey 2006; Madella et al. 2013; Neef et al. 2012). Phytoliths were described using the International Code for Phytoliths Nomenclature (ICPN—Madella et al. 2005), whereas starch grains were described according to the International Code for Starch Nomenclature (ICSN 2011).

Results

Fire-related contexts

Charred macroremains from Shikarpur were scarce and generally poorly preserved (Table 3; Fig. 2). Charred grass (Poaceae) remains included 31 grains of small millets, of which 22 belonged to the general SEB type (*Setaria*, *Echinochloa* and *Brachiaria*) (Fig. 2a) and nine were identified no further than *small millets* due to severe damage. Chaff from *Oryza* (Fig. 2b) and *Hordeum* were also found. Further recovered grasses included half a charred grain of *Coix lacryma-jobi* L. (Job's tears) (Fig. 2c) and 10 mineralised full inflorescences of *B. ramosa* (Fig. 2d-e). Pulses (Fabaceae) were also present, and 19 seeds morphologically comparable to *Vigna radiata* and *V. mungo* were found (Fig. 2f). Morphometric analyses were not conclusive, but the generally small seed size (average 1.15 × 0.87 mm) suggests a wild species of *Vigna* (Fuller and Harvey 2006). Moreover, leaf fragments

Table 3 Results of the macroremains analysis from fire-related contexts. + = present

	Ash 1	Ash 2	Ash 3	Pit 1	Pit 2	BA 1	BA 2	Hearth 1	Hearth 2
Aizoaceae									
Trianthema sp.	1	1	.	2	.	.	.	29	1
Amaranthaceae									
Chenopodium sp.	1	1	.	1	.	.	20	.	.
Cyperaceae									
cf. *Scirpus* sp.	.	1	.	1	2	1	1	.	.
Fabaceae									
Vigna sp.	1	1	.	10	2	.	3	.	2
Leaf fragments	.	+	.	+	.	.	.	+	+
Poaceae									
Panicoideae									
Brachiaria ramosa (min.)	.	.	.	10	.	.	.	.	.
SEB type	1	1	.	16	2	1	.	.	1
Small millet indet.	.	1	.	4	2	.	.	1	1
Coix lacryma-jobi	.	.	.	1	.	.	.	.	.
Oryza sp. spikelet base	.	.	.	.	1	.	.	.	.
Pooideae									
Hordeum vulgare rachis	.	.	.	.	1	.	.	.	.
Cerealia chaff	.	.	.	3	.	.	.	.	1
Parenchyma fragments	+	+	.	+	+	.	.	+	+

from an unidentified member of the Fabaceae were recovered from four contexts. Other finds included several weeds (*Trianthema* sp. and *Chenopodium* sp.) (Fig. 2g–h), six sedge grains and several parenchyma fragments from tubers.

The analysis of single-cell phytoliths (Table 4, Fig. 3a) showed a predominance of grass morphotypes (91.99 % Poaceae) over non-grass (1.51 %). Undetermined phytoliths, a group that includes non-diagnostic as well as unidentified phytoliths, accounted for 6.50 % of the single-cell phytoliths. The non-grass phytoliths were mainly morphotypes from dicotyledons and monocotyledons, such as palms (Arecaceae) and sedges (Cyperaceae) (Fig. 4a–c). Among grass phytoliths, long (elongated) cells and bulliforms offer anatomical information, whereas short cells are taxonomically diagnostic at subfamily level. Anatomical and taxonomical information is considered separately, so percentages presented below are calculated independently for the anatomically and the taxonomically diagnostic phytoliths. Leaf/culm phytoliths (bulliforms and psilate/sinuate elongated cells; 75.38 %) (Fig. 4d) outweigh inflorescence phytoliths (11.08 %) and anatomically non-diagnostic elongated cells (13.54 %). Short cell panicoid morphologies predominate (46.09 %) over chloridoid (15.42 %) and pooid (12.47 %), with non-attributable morphologies accounting for 26.02 % of the total. A total of 111 grass multi-cell phytoliths (silica skeletons) were encountered in the fire-related contexts, with 65 from leaves/culms, 44 from inflorescences and 2 anatomically non-diagnostic. Based on the morphology of elongated and short cells, 10 inflorescence silica skeletons were identified as panicoids. In particular, this silica skeleton morphology typically occurs in the external parts of the inflorescence (glumes, lower lemma and lower palea) of small millets (Fig. 5).

Starch grains were also scarce (n = 46) and only four morphotypes were identified (Table 4; Fig. 3a). The most common typology (52.17 %), further divided into three sub-types according to size, has a Panicoideae faceted polyhedral morphology. Type 1 grains are small (5-10 µm) to very small (<5 µm), characteristic of small millets (Fig. 6a) and rice, whereas Type 3 grains (>20 µm) occur mostly in big millets such as *Sorghum bicolor* (L.) Moench. (sorghum), *Pennisetum glaucum* (L.) R.Br. (pearl millet) and *C. lacryma-jobi* (Fig. 6b) (Madella et al. 2013 and references therein). Type 2 grains are of medium size (10–20 µm) and they can represent any of the previous taxa within the Panicoideae. The second-most frequent type (28.26 %) has discoidal grains, with a smooth surface and lamellae, characteristics of the tribe Triticeae (Pooideae, Poaceae) (Fig. 6c–d). Other finds include seven ovoid grains with a smooth surface, lamellae and a linear hilum diagnostic of the Faboideae (Fabaceae) (Fig. 6e–f); and two small grains that could belong to the Triticeae but which are also present in other taxa, and are therefore classified as cf. Triticeae.

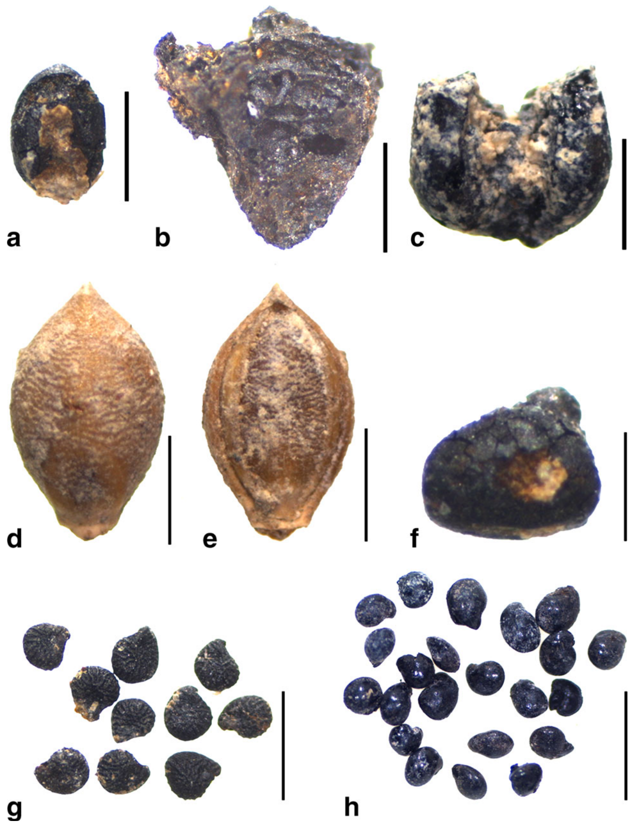


Fig. 2 Macrobotanical remains recovered from Shikarpur. **a** charred caryopsis of a SEB type small millet, **b,** charred spikelet base of *Oryza* sp., **c** half charred caryopsis of *Coix lacryma-jobi* L. (Job's tears), **d** dorsal and **e** ventral view of a mineralised inflorescence of *Brachiaria ramosa* (L.) Stapf. (browntop millet), **f** charred seed of *Vigna* sp., **g** charred grains of *Trianthema* sp., **h** charred grains of *Chenopodium* sp. *Scale bar* 1 mm in **a**–**f** and 2 mm in **g**–**h**

Grinding stones

Plant microremains were abundant in the grinding implements from Shikarpur. Phytolith concentrations were very high compared to other published analyses of grinding stones (e.g. Portillo et al. 2009). The pestle showed particularly high values, whereas Hand 3 is an exception with an extremely low presence of phytoliths (Table 2). The phytolith assemblage from Hand 3, unlike other grinding tools, was dominated by bulliforms and trichomes (included within the undetermined taxa). These morphotypes are, overall, thicker than elongated and short cells, and thus more resistant to taphonomic processes that may have affected the phytolith assemblage from Hand 3 (Madella and Lancelotti 2012). Moreover, this is the sole sample where phytolith concentration is lower than its control. For these reasons, this assemblage might not represent the original phytolith input and has therefore been excluded from the percentages presented below (Fig. 3b).

The analysis of single-cell phytoliths (Table 5) shows similar results to samples from fire-related contexts. Grass morphotypes predominate (91.81 %) and, among grasses, panicoids (39.23 %) are more represented than chloridoids (16.85 %) and pooids (19.60 %). The anatomical analysis also shows the predominance of leaf/culm phytoliths (66.56 %) over inflorescence morphotypes (26.43 %). The presence of sedge and palm phytoliths is worthy of note (although the latter were only encountered in Hand 3). Silica skeletons were scarce and only 25 of these were encountered, among which one was identified as being from pooid grasses.

A total of 650 starch grains were recovered from grinding stones (Table 5; Fig. 3b), most of which belong to the Panicoideae (51.69 %) (Fig. 7a–b) and the Faboideae (30.92 %) (Fig. 7c). Triticeae (2.46 %) (Fig. 7d) and cf. Triticeae (4.15 %) grains were also recovered, although the former were much less common. Three morphotypes that were not encountered in fire-related contexts were recovered from grinding stones: (a) 30 spherical grains with a linear hilum and lines radiating from the centre, attributed to cf. Panicoideae (Fig. 7e); (b) 18 ovoid grains with a smooth surface, a regular extinction cross and an eccentric small vacuole hilum (Fig. 7f–g), most probably from a tuberous plant; and (c) one bell-shaped grain with an eccentric, linear hilum (Fig. 7h–i) that occurs in roots and palms. Finally, 21 starch grains could not be identified due to severe damage.

Discussion

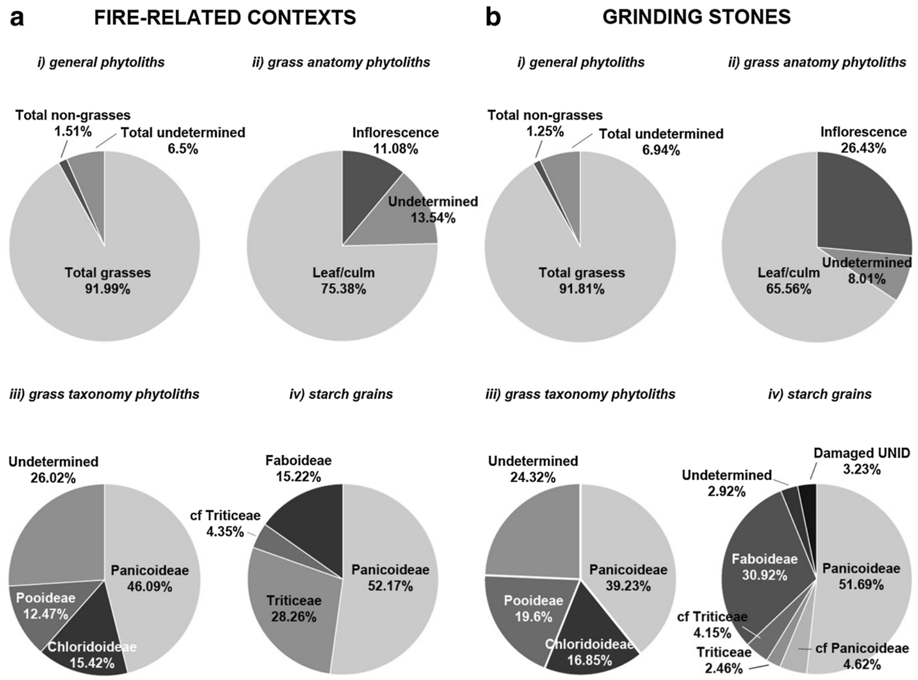
Integrating macro- and microbotanical remains

The scarcity of charred macroremains at Shikarpur, linked to the dry-wet cycles caused by the monsoon climate of this region and the high salinity of the soils, highlights the difficulty of assessing the plant use strategy solely based on this evidence. The few data gathered from macroremains show that small millets appear together with common weeds of millet, such as *Trianthema* sp. and *Chenopodium* sp., suggesting that small millets were being cultivated and not simply gathered. Most charred small millets are identified as SEB type, a group within the tribe Paniceae (Panicoideae, Poaceae). Several species within this group are native to South Asia, whereas *Setaria italica* (L.) P. Beauv. (foxtail millet) was domesticated in China (Nasu et al. 2007). The timing of the arrival of *S. italica* in northwest South Asia is controversial. Some researchers claim that it was already present in Early Harappan times, before 2600 BC (Pokharia et al. 2014 and references therein), while Fuller (2006) suggested that the finds reported as *S. italica* are instead *Brachiaria ramosa*, which is morphologically very similar to *Setaria* spp. Fuller advocates that *S. italica* and *Panicum miliaceum* L. (common millet) were not

Table 4 Results of phytolith and starch grain analyses from fire-related contexts

	Ash 1	Ash 2	Ash 3	Pit 1	Pit 2	BA 1	BA 2	Hearth 1	Hearth 2a	Hearth 2b	Oven
Phytoliths											
Single cells											
Monocotyledons											
Arecaceae	.	.	.	.	1	.	.	.	.	.	.
Cyperaceae	.	.	1	.	.	.	.	2	.	.	.
Poaceae											
Bulliforms (leaf)	1	8	53	9	11	23	22	13	27	30	13
Elongated cells											
Inflorescence	13	9	5	2	4	6	3	14	5	4	7
Leaf/culm	21	33	28	10	31	20	24	33	41	19	20
Undetermined	8	2	7	3	12	6	4	15	6	12	13
Short cells											
Chloridoideae	25	26	24	43	35	44	34	28	30	42	40
Panicoideae	128	111	68	135	97	102	89	86	87	94	112
Pooideae	29	33	25	24	23	32	30	33	27	17	27
Undetermined	69	46	39	52	68	47	77	60	49	57	62
Dicotyledons	.	7	11	4	4	4	4	2	6	3	2
Undetermined taxa	13	27	38	15	14	16	19	16	25	25	7
Total single cells	307	302	299	297	300	300	306	302	303	303	303
Silica skeletons											
Inflorescence											
Chloridoideae	.	.	.	1	.	.	.	.	.	.	.
Panicoideae	1	2	.	2	1	1	.	.	.	.	3
Undetermined	5	5	.	2	4	2	5	.	2	.	8
Leaf/culm											
Chloridoideae	.	1	.	.	1	.	.	.	.	.	.
Panicoideae	.	1	.	.	1	.	.	.	.	.	.
Undetermined	6	12	1	3	7	13	6	.	5	.	8
Undetermined	1	.	.	.	.	1	.	.	.	.	.
Total silica skeletons	13	21	1	8	14	17	11	.	7	.	19
Starch grains											
Fabaceae											
Faboideae	.	.	1	1	1	1	.	.	.	2	1
Poaceae											
Panicoideae											
Type 1 (<10 µm)	.	.	.	.	.	.	.	4	1	.	.
Type 2 (10-20 µm)	.	1	1	2	.	.	.	2	3	3	1
Type 3 (>20 µm)	.	2	.	2	.	1	.	.	1	.	.
Pooideae											
Triticeae	3	2	.	2	.	1	4	.	1	.	.
cf Triticeae	.	.	.	1	1	.	.	.	.	.	.
Total starch grains	3	5	2	8	2	3	4	6	6	5	2

Fig. 3 Percentages of single-cell phytoliths and starch grains recovered from **a** fire-related contexts, **b** grinding stones. *i* single-cell phytoliths, *ii* anatomically diagnostic grass phytoliths (elongated cells and bulliforms), *iii* taxonomically diagnostic grass phytoliths (short cells), *iv* starch grains



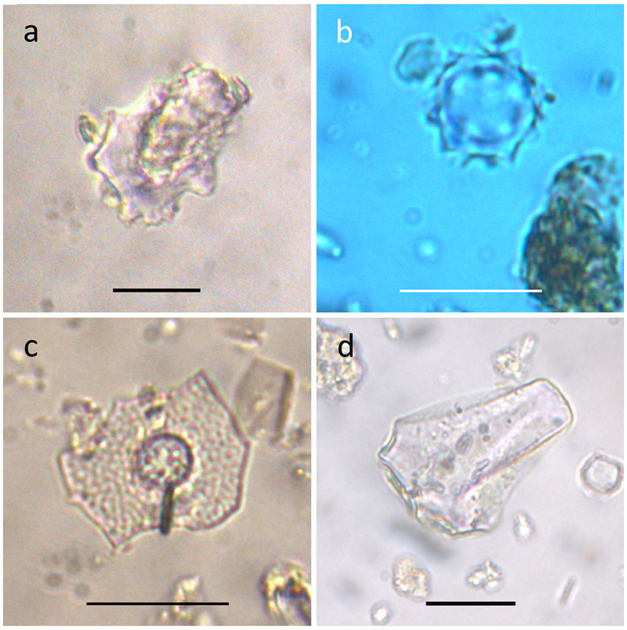


Fig. 4 Single-cell phytoliths recovered from Shikarpur. **a** irregular phytolith from a dicotyledonous plant, **b,** globular echinate phytolith from a palm (Arecaceae), **c** scrobiculated cone phytolith from a sedge (Cyperaceae), **d** bulliform phytolith from a grass (Poaceae) leaf. *Scale bars* are 20 µm

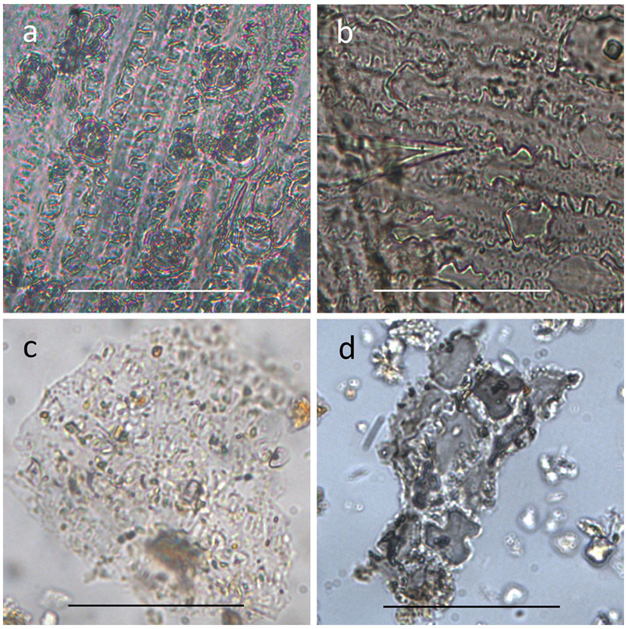


Fig. 5 Modern (**a**–**b**) and archaeological (**c**–**d**) multi-cell phytoliths (silica skeletons) recovered from Shikarpur: **a** lower lemma from *Brachiaria ramosa* (L.) Stapf. (browntop millet), **b** lower glume from *Echinochloa colona* (L.) Link (shama millet), **c**–**d,** panicoid silica skeletons from fire-related contexts. *Scale bars* are 50 µm

present in South Asia until Post Urban Harappan times, after 1900 BC. Charred remains from Shikarpur are not conclusive, but the presence of 10 mineralised *B. ramosa* grains suggests the undeniable presence of this species, although its importance is difficult to estimate.

The evidence from other proxies, phytoliths and starch grains, also suggests that small millets were staples for the inhabitants of Shikarpur. No silica skeletons from the upper lemma and palea of small millets were encountered, which are diagnostic to species level (Lu et al. 2009; Zhang et al. 2011). However, the presence of silica skeletons from the

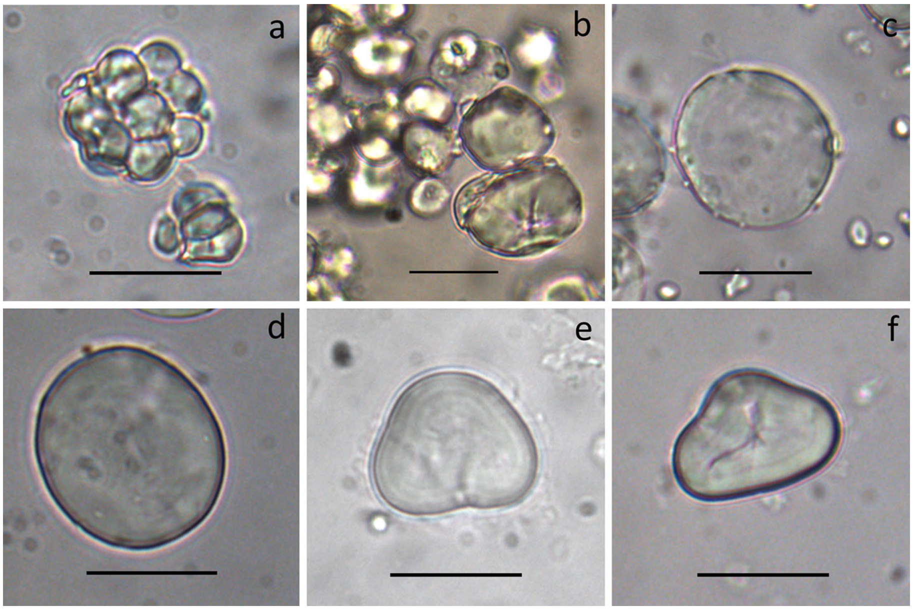


Fig. 6 Modern starch grains from the reference collection. **a** *Brachiaria ramosa* (L.) Stapf. (browntop millet), **b** *Coix lacryma-jobi* L. (Job's tears), **c** *Hordeum vulgare* L. (barley), **d** *Triticum aestivum* L. ssp. *sphaerococcum* (Perc.) MK. (dwarf wheat), **e** *Vigna radiata* (L.) R.Wilczek (mung bean), **f** *Vigna mungo* (L.) Hepper (black gram). *Scale bars* are 20 µm

external parts (glumes, lower lemma and lower palea) suggests that small millet processing was taking place at the settlement. The significant presence of Type 1 Panicoideae starch grains (<10 µm) and the scarcity of inflorescence silica skeletons in grinding implements implies that these tools were used to mill clean small millet grains for flour and not for dehusking. This highlights the use of millets in Shikarpur as flour, possibly for bread making, but not as whole grain food. These starch grains are also produced in *Oryza* (Yang and Perry 2013), but the only rice evidence from the macroremains is a single charred spikelet base found in Pit 2 and there is no evidence of rice phytoliths. Macroremains and missing phytoliths therefore reinforce the hypothesis that Type 1 Panicoideae starch grains are from small millets.

The presence of Type 3 Panicoideae starch grains (>20 µm) seems to suggest that big millets were also milled at Shikarpur. The presence of African millets (*Sorghum bicolor*, *Pennisetum glaucum* and *Eleusine coracana*) in South Asia during the 3rd millennium BC seems to be dubious (Fuller 2003) and it is possible that Type 3 morphologies are from *Coix lacryma-jobi*, the grains of which were found in Pit 1, Shikarpur, and other Chalcolithic sites in northern Gujarat (authors' unpublished data). This plant is still a minor food and fodder crop in some parts of India (Arora 1977).

Triticeae starch grains were also present at Shikarpur. The damage caused by grinding and the small number of grains recovered, 29 grains in total, prevents a more specific taxonomical identification based on surface features as suggested by Yang and Perry (2013). Most of the recovered grains (75.86 %) were larger than >20 µm, suggesting that they were from *Triticum*, *Hordeum*, *Secale*, *Agropyron* or *Aegilops* (Yang and Perry 2013). Moreover, plants from the Triticeae are not native to Gujarat (Fuller 2006) and, according to macrobotanical evidence from excavations of other archaeological sites, the only crops from this tribe which were consumed in this region during Harappan times were *Triticum* and *Hordeum* (Fuller and Madella 2001). Therefore, the Triticeae starch grains identified in both fire-related contexts and grinding stones can be attributed to *Triticum*/*Hordeum*. The macrobotanical evidence for the processing and consumption of these cereals is limited to some charred chaff but, once more, the multi-proxy approach highlights their presence and use in the settlement, even as minor components of the diet.

The combined botanical evidence demonstrates that pulses also played an important role in the diet of the inhabitants at Shikarpur, who seem to have consumed wild *Vigna* taxa. The presence of Fabaceae leaf fragments in fire-related contexts could suggest that the wild *Vigna* grains had entered the archaeobotanical record as fuel, either directly or via animal dung (Lancelotti and Madella 2012). However, the significant presence of Faboideae starch grains on grinding stones makes clear that at least one wild *Vigna* taxon was part of the people's diet. Similarly, sedge nutlet phytoliths from grinding stones, despite being scarce, suggest that sedges may have been processed in small quantities for human consumption. Finally, tuberous plants and roots also appear in the assemblage from Shikarpur and they were probably consumed both whole (charred parenchyma) and ground (starch grains from grinding tools and globular echinate phytoliths).

Table 5 Results of phytolith and starch grain analyses from grinding stones

	Quern 1	Quern 2	Quern 3	Quern 4	Quern 5	Quern 6	Quern 7a	Quern 7b	Quern 8	Quern 9a	Quern 9b	Hand 1	Hand 2	Hand 3	Hand 4	Hand 5	Hand 6	Hand 7	Mortar	Pestle
Phytoliths																				
Single cells																				
Monocotyledons																				
Arecaceae	.	.	.	.	.	.	.	.	.	.	.	.	.	3	.	.	.	.	.	.
Cyperaceae	1	.	3	.	1	.	.	.	.	.	.	.	.	.	.	3	.	.	.	.
Poaceae																				
Bulliforms (leaf)	18	22	20	14	7	22	20	22	18	21	31	25	22	141	12	26	24	17	17	15
Long cells																				
Inflorescence	5	6	21	22	16	10	15	14	7	7	11	14	13	4	15	20	13	18	16	11
Leaf/culm	10	10	24	17	6	6	6	8	3	15	10	16	21	32	26	18	13	12	27	9
Undetermined	2	9	1	6	14	3	3	.	.	1	2	7	8	9	7	1	1	9	2	1
Short cells																				
Chloridoideae	31	34	53	44	33	61	48	32	40	34	41	31	32	8	35	32	42	34	36	35
Panicoideae	111	101	102	105	79	67	84	78	78	84	57	100	102	16	101	77	70	92	85	122
Pooideae	39	25	36	44	53	50	34	57	68	49	39	39	36	6	34	58	59	51	37	39
Undetermined	54	72	46	34	72	58	79	78	54	64	77	51	36	8	37	40	48	47	45	59
Dicotyledons	3	7	2	4	.	2	.	5	2	2	.	5	7	8	5	2	4	2	11	1
Undetermined taxa	25	18	15	8	22	20	19	13	30	27	31	14	22	102	26	25	28	19	23	14
Total single cells	299	304	323	298	303	299	308	307	300	304	299	302	299	337	298	302	302	301	299	306
Silica skeletons																				
Inflorescence																				
Pooideae	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.
Undetermined	.	.	.	.	1	.	1	.	.	.	.	1	.	.	1	.	.	.	.	8
Leaf/culm																				
Undetermined	.	.	2	.	2	.	.	.	1	.	.	2	.	4	1	.	.	.	.	2
Undetermined	.	.	1	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.
Total silica skeletons	.	.	3	.	3	.	2	.	1	.	1	3	.	4	2	.	.	.	.	10
Starch grains																				
Fabaceae																				
Faboideae	3	.	4	20	5	11	12	4	17	18	13	8	19	5	3	14	10	15	5	16
Poaceae																				
Panicoideae																				
Type 1 (<10 μm)	.	.	89	.	41	1	.	.	15	.	10	.	.	.	.	4	12	1	.	5
Type 2 (10-20 μm)	1	1	.	3	18	.	8	3	4	2	1	15	19	1	9	18	6	1	2	18
Type 3 (>20 μm)	.	1	.	.	2	.	1	.	.	.	.	5	4	.	2	7	.	1	.	5
cf. Panicoideae	1	1	1	1	.	5	2	1	1	5	.	.	2	.	4	5	.	1	.	.
Pooideae																				
Triticeae	1	.	.	.	1	.	1	.	.	.	3	2	.	1	2	.	.	.	4	1
cf. Triticeae	.	.	1	.	1	.	9	2	.	.	2	1	3	1	1	1	.	3	1	1
Root/palm undet.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.
Tuber undet.	1	.	2	.	.	.	.	.	1	.	.	1	2	.	2	7	2	.	.	.
Damaged UNID	.	2	1	.	1	2	1	2	7	.	.	.	1	1	.	1	1	1	.	.
Total starch grains	7	5	98	24	69	19	33	12	45	25	29	32	50	9	23	57	31	24	12	46

Subsistence strategies at Shikarpur

The multi-proxy approach shows that the subsistence strategy of the inhabitants of Shikarpur was based on local summer crops, mostly small millets (*B. ramosa* and some other taxa) but also a wild *Vigna* legume. Taking into account the environmental settings of this region, with low water availability, high inter-annual variability including droughts, short cropping period and high salinity, the combination of small millets and wild pulses would probably have constituted the most profitable land use strategy. The possibility of the cultivation of wild *Vigna* taxa, which

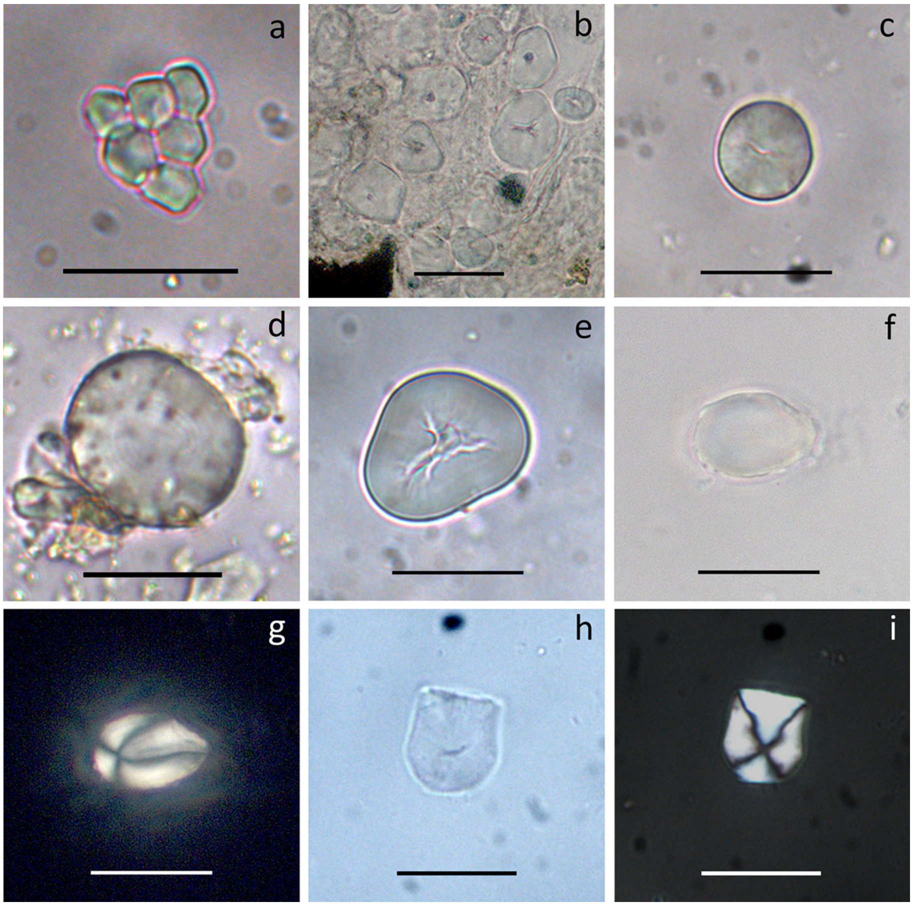


Fig. 7 Starch grains recovered from Shikarpur. **a** Panicoideae Type 1 (<10 µm) grains, **b** Panicoideae Type 2 (10–20 µm) and Type 3 (>20 µm) grains, **c** cf. Panicoideae grain, **d** Triticeae grain, **e** Faboideae grain, **f**–**g** tuberous grain, **h**–**i** root/palm grain. *Scale bars* are 20 µm. Images **g** and **i** are under cross-polarised light

could also have improved the soil by nitrogen enrichment, cannot be discarded completely. Other resources such as rice and sedges and also some kinds of roots and tubers also seem to have been consumed, possibly as condiments or spices.

Triticum and *Hordeum*, which were staple crops in the core Harappan areas, were scarcely present at Shikarpur. Macrobotanical evidence is limited to one *Hordeum* rachis. Pooideae phytoliths were only marginally present both in all analysed contexts and tools. The best evidence for *Triticum*/*Hordeum* consumption comes from Triticeae starch grains which were recovered from grinding stones. This minor presence of big grain C3 cereals at Shikarpur might represent a local, small-scale cultivation, which seems unlikely in the absence of chaff phytoliths or, most probably, the trading between Harappan settlements set in different ecological regions of which Shikarpur was part (Bahn and Ajithprasad 2008; Gadekar et al. 2014). *Triticum* and *Hordeum* were not the main staples in northern Gujarat, and their use may be related to cultural preferences of the inhabitants of Shikapur as part of the area of Harappan influence.

Conclusions

We believe that a combined approach, in which several botanical proxies and a broad-spectrum sampling strategy are used together, is the best possible way to explore diet and plant use strategies in past societies. This paper has shown how effective this method can be and how the information obtained can be enhanced. The combined information from the different deposits and grinding tools at Shikarpur highlights not only the presence at the site of various taxa, both cultivated and wild, but also the pathways of their use. The macrobotanical evidence helped, regardless of its paucity, in identifying some of the staple grains, such as the small millets, and some secondary grains such as the *Vigna* sp. wild pulses, which could have been interpreted as part of the weed or fuel (dung) assemblage. However, the starch from the grinding stones undeniably shows that these seeds were ground to flour and therefore that they were part of the diet. The microbotanical remains broadened the information on the plant spectrum used for food such as sedges and tubers, as the remains were connected to processing with grinding stones. Finally, it is remarkable to see how the different proxies can reinforce and complement each other; as is the case of the wild *Vigna* identified in the macroremains for which the microremains strongly highlighted their predomestic character.

Acknowledgments This research benefited from discussions with P. Ajithprasad, H. Barton and the participants of the 16th Conference of the IWGP in Thessaloniki (Greece). Thanks are due to the members of the Department of Archaeology and Ancient History, MSU Baroda, for helping during the 2012 fieldwork at Shikarpur, and the Archaeological Survey of India for granting permission for the excavation. Some of the modern reference seeds are from the US Department of Agriculture (USDA) gene bank. JJGG acknowledges funding from a JAE-Predoc doctoral research grant (Spanish National Research Council and European Social Fund) and CL from the SimulPast project, funded by the Spanish Ministry for Science and Innovation (CSD2010-00034).

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