Current Anthropology Volume 57, Number 2, April 2016

Millets and Herders

The Origins of Plant Cultivation in Semiarid North Gujarat (India)

by Juan José García-Granero, Carla Lancelotti, Marco Madella, and P. Ajithprasad

Botanical evidence suggests that North Gujarat (India) was a primary center of plant domestication during the mid-Holocene. However, lack of systematic archaeobotanical research and significant taphonomic processes have so far hampered the possibility of substantiating this hypothesis. This paper explores the role of plants in the subsistence strategies of early-middle Holocene populations in this semiarid region and the processes leading to plant cultivation. To do so, we carry out a multiproxy archaeobotanical study—integrating macro and microbotanical remains—at two hunter-gatherer and agropastoral occupations. The results show that the progressive weakening of the Indian summer monsoon ca. 7,000 years ago compelled human populations to adopt seminomadic pastoralism and plant cultivation, which resulted in the domestication of several small millet species, pulses, and sesame.

Understanding how human societies adapted to environmental and climatic variability in the past is fundamental to face present and future climatic events, particularly in highly vulnerable arid and semiarid regions (Brooks, Grist, and Brown 2009; Costanza et al. 2007). Archaeological research in marginal areas has revealed how humans reacted to changing ecological conditions by integrating short-term coping mechanisms and long-term adaptive strategies, such as innovation, enhanced social networks, increased mobility, and, ultimately, migration (e.g., An et al. 2005; Dillehay and Kolata 2004; Kuper and Kröpelin 2006; Rosen and Rivera-Collazo 2012; Spielmann et al. 2011).

North Gujarat (northwestern India) is a semiarid ecotone (annual precipitation of 400–600 mm) between the Thar Desert and the semihumid South Gujarat (fig. 1). The region is characterized by a strong seasonality—the Indian summer monsoon regime, in which most of the rainfall occurs between June and September—as well as a high variability in interannual precipitation (Balbo et al. 2014), and it is prone to both severe droughts and floods every few years (Parthasarathy et al. 1987).

North Gujarat can be divided into four physiographical units: the uplands (Aravalli Hills), the silt belt, the dune-interdune area, and the Little Rann of Kachchh (Balbo et al. 2013; Conesa et al. 2015). Archaeological evidence is mostly found in the dune-interdune area, which is characterized by stabilized dunes from the retreat of the Thar Desert ca. 7,000 years ago (Balbo et al. 2013 and references therein). Interdunal depressions accumulate monsoon rainwater and retain high moisture levels for a good part of the year, offering water to pastoral and agricultural activities. The major agricultural season in North Gujarat is the summer *kharif*, which involves sowing with the first monsoonal rains (June-July) and harvesting in October-November (Reddy 1997). Winter *rabi* cultivation (crops grown between November and April) occurs only with the aid of modern irrigation, although dry farming is possible in some interdunal depressions (Bhan 1994).

During the early and middle Holocene, hunter-gatherer and agropastoral communities occupied North Gujarat. Hunter-gatherer occupations are characterized by the presence of a microlithic industry and the absence of ceramics and are often called mesolithic (e.g., Sankalia 1987) or microlithic (Patel 2009) in the literature. More than 2 decades ago, scholars identified the existence of autochthonous food-producing communities in North Gujarat and Kachchh dating to the mid fourth millennium BC (Ajithprasad 2002; Ajithprasad and Sonawane 2011; Patel 2009; Possehl 1992; Sonawane and Ajithprasad 1994). This cultural tradition, mainly defined by

---

Juan José García-Granero is a Postdoctoral Fellow at Complexity and Socio-Ecological Dynamics Research Group (CaSEs) and in the Department of Archaeology and Anthropology, Institució Milà i Fontanals, Consejo Superior de Investigaciones Científicas (IMF-CSIC; C/Egipcíaques 15, 08001 Barcelona, Spain [jjgarciagranero@yahoo.es]). **Carla Lancelotti** is a Postdoctoral MSC-EU Fellow at CaSEs in the Department of Humanities, Universitat Pompeu Fabra (c/Trias Fargas 25-27, 08005 Barcelona, Spain). **Marco Madella** is ICREA Research Professor at CaSEs in the Department of Humanities, Universitat Pompeu Fabra (c/Trias Fargas 25-27, 08005 Barcelona, Spain), and in the Department of Archaeology and Anthropology, IMF-CSIC (C/Egipcíaques 15, 08001 Barcelona, Spain). **P. Ajithprasad** is Professor in the Department of Archaeology and Ancient History of the Maharaja Sayajirao University of Baroda, Pratapgunj (390002 Vadodara, Gujarat, India). This paper was submitted 11 XI 14, accepted 16 IV 15, and electronically published 14 III 16.

0011-3204/2016/5702-0002$10.00. DOI: 10.1086/685775

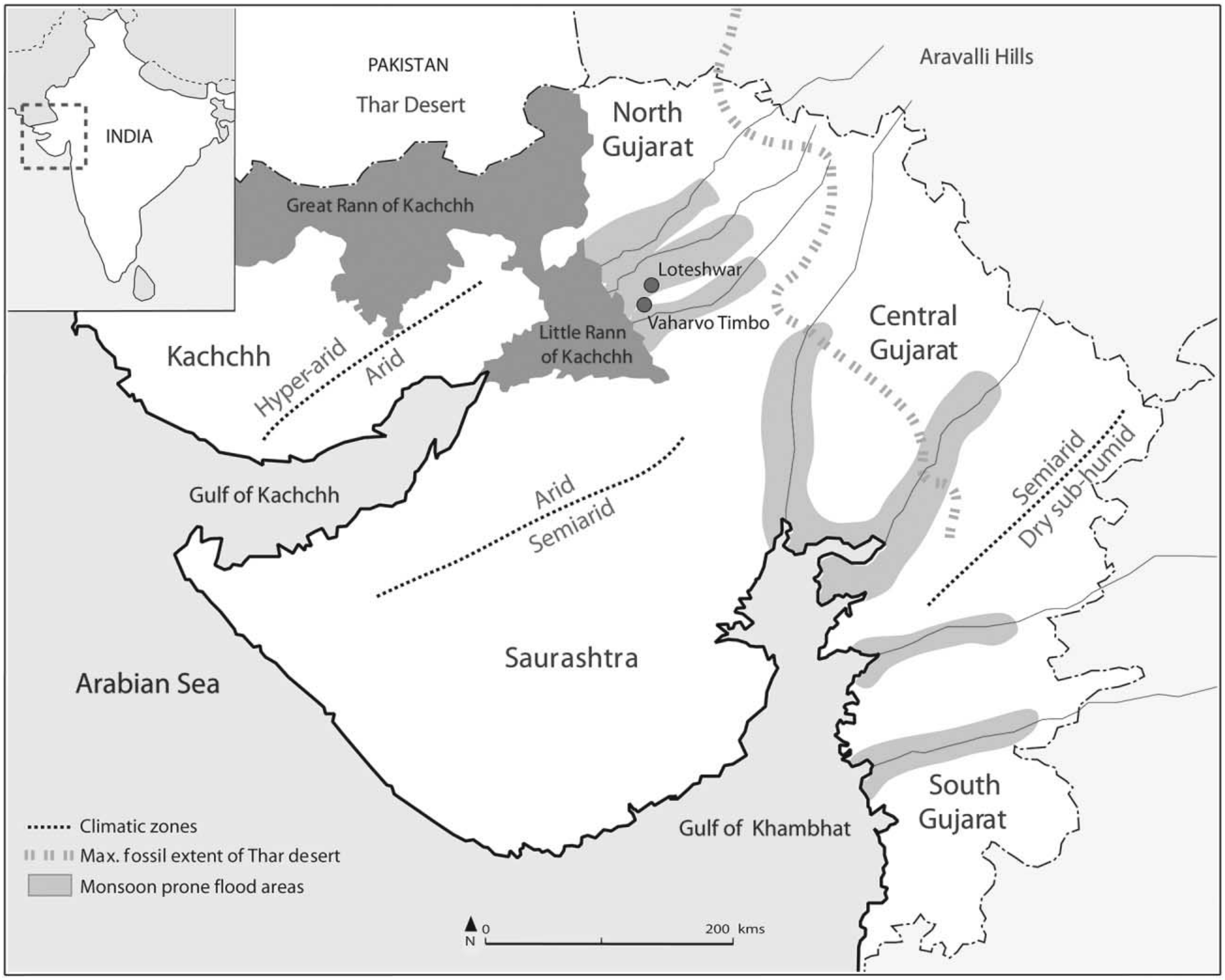

Figure 1. Map of North Gujarat, showing climatic zones, the maximum fossil extent of the Thar Desert, monsoon-prone flood areas, and the location of Loteshwar and Vaharvo Timbo. Image by Francesc C. Conesa. A color version of this figure is available online.

a distinctive pottery assemblage, was named Anarta after the traditional name of North Gujarat. The importance of pastoral activities for Anarta communities seems clear (Ajithprasad and Sonawane 2011 and references therein); however, the role of plant resources in their subsistence strategies remains poorly understood (Sonawane 2000:143). During the mid third millennium BC a series of walled urban settlements with characteristic Harappan material culture from the Indus Civilization (northwest South Asia) appear along trade and travel corridors throughout Gujarat (Chase et al. 2014). Archaeobotanical research at Harappan (ca. 2500–1700 BC) settlements in Saurashtra (e.g., Reddy 1997; Weber 1999) shows an agricultural system based on native small millets and tropical pulses, as opposed to the Near Eastern crop package characteristic of the core Indus Valley (Fuller and Madella 2002).

The aim of this paper is to explore the role of plants in the subsistence strategies of pre-Harappan populations in North Gujarat, with a focus on testing Fuller's (2006) hypothesis on the origins of cultivation in this semiarid region. To do so, we discuss the results of a multiproxy study—integrating macro and microbotanical remains—from two early-middle Holocene occupations: Loteshwar, the most thoroughly investigated Mesolithic and Anarta site, and the nearby hunter-gatherer occupation of Vaharvo Timbo.

Case Study

Loteshwar (23°36′1.8″N, 71°50′11.8″E), locally known as Khari no Timbo, is located about 500 m east of the Khari River (fig. 1). The excavation conducted by the Department of Archaeology and Ancient History of the Maharaja Sayajirao University of Baroda in the early 1990s uncovered two occupational levels: a Mesolithic hunter-gatherer occupation with superimposed Anarta Chalcolithic deposits (Mahapatra 1995). A series of accelerator mass spectrometry (AMS) ^{14}C determinations (Ajithprasad 2002, 2004; Patel 2009; Sonawane and Ajithprasad 1994) place Loteshwar as one of the earliest Holocene hunter-gatherer occupations in northwestern India (7168–4703 cal BC). The Anarta occupation of the dune (3681–2243 cal BC) predates the establishment of Urban Harappan communities in Gujarat (Ajithprasad and Sonawane 2011). Furthermore, the study of faunal remains (Patel 2009) suggested that North Gujarat had the potential for local domestication of *Bos indicus* (zebu).

The North Gujarat Archaeological Project (NoGAP), a collaboration between the Maharaja Sayajirao University of Baroda and the Institució Milà i Fontanals, Consejo Superior de Investigaciones Científicas (Spain; Madella et al. 2010), excavated a 4 × 4-m trench at Loteshwar in 2009. The stratigraphic sequence uncovered features comparable to those identified in the previous excavations: an aceramic hunter-gatherer (Mesolithic) occupation of about 80 cm and an Anarta deposit of about 60 cm (Madella et al. 2011), separated by a mixed level of ca. 40 cm with a few small potsherds. The hunter-gatherer and the mixed levels were cut by three Anarta pits down to 50/170 cm, with a lining of plant material preserved as pure phytoliths (Balbo et al. 2015).

Vaharvo Timbo (23°33′17.05″N, 71°48′12.01″E) lies 6 km southwest of Loteshwar (fig. 1). The site, reported in the early 1980s as Wasaro no Timbo (Bhan 1994, appendix), was excavated by the NoGAP team in 2011. Two 4 × 4-m trenches were opened (Madella et al. 2012): trench 1 had a uniform aceramic hunter-gatherer occupation of ca. 100 cm, with three pits of different size and shape down to about 135 cm; trench 2 had also an aceramic deposit cut by a human burial. The grave goods of the burial included two full Early Harappan Sindh pots (ca. 2800–2600 BC; Ajithprasad 2011).

The archaeological deposits uncovered by the NoGAP excavations at Loteshwar and Vaharvo Timbo were AMS dated (table 1). At Loteshwar, the dates show a shorter Anarta occupation of the dune (ca. 2700–2300 cal BC) in respect to the deposits from the previous excavations (ca. 3700–2250 cal BC). The Mesolithic and mixed levels were also dated ca. 2700–2300 cal BC, suggesting that there was a postdepositional infiltration (or mixing as suggested in the mixed level) of wood charcoal from the uppermost Anarta deposits. The dates from Trench I at Vaharvo Timbo (ca. 5600–5000 cal BC) show a relatively long hunter-gatherer occupation of the dune, contemporaneous with the end of the hunter-gatherer occupation at Loteshwar (Ajithprasad 2004; Patel 2009; Sonawane and Ajithprasad 1994).

Material and Methods

A systematic sampling strategy for the recovery of macro- (seeds and charred wood) and microbotanical (phytoliths and starch grains) remains was carried out for the entire stratigraphic sequences of the sites (tables 1, 2). Bulk samples were collected from each excavation spit (ca. 10 cm) on a 2 × 2-m grid and macroremains recovered by bucket flotation with a 0.25-mm mesh. Sediment samples (ca. 50 g) were separated before flotation for microbotanical and soil pH analyses. All macroremains in the fraction >0.5 mm were sorted using a Leica EZ4 D stereoscope. Microremains from sediments and grinding tools were extracted following the protocols described by García-Granero et al. (2016) and observed at ×200 and ×630 magnifications with a Leica DM 2500 microscope equipped with a Leica DF 470 camera for microphotography.

When possible, 300 identifiable single-cell phytoliths were counted, and in samples with very low phytolith presence, the whole slide was scanned. Multicell phytoliths (silica skeletons) were counted independently and photographed. Phy-

Table 1. Sediment samples analyzed in this study and radiocarbon estimations

Site and ID	Period	Description	Dated material	^{14}C age (year BP)	2σ cal age (year BC)	Lab code
Loteshwar:						
Dep 1	Anarta	General deposit	Wood charcoal	3,975 ± 35	2577–2438	2219.1.1
Dep 2	Mixed	General deposit	Wood charcoal	3,915 ± 35	2487–2290	2221.1.1
Dep 3	Mesolithic	General deposit	Wood charcoal	4,075 ± 35	2701–2557	2223.1.1
Pit 1	Anarta	SE pit	…	…	…	…
Pit 2	Anarta	NE pit	…	…	…	…
Pit 3	Anarta	NW pit	Wood charcoal	3,925 ± 35	2491–2295	2225.1.1
Ash 1	Anarta	NE ashy patch	Wood charcoal	4,055 ± 35	2678–2475	2220.1.1
Ash 2	Anarta	NW ashy patch	…	…	…	…
Vaharvo Timbo:						
Dep 1	Mesolithic	General deposit	…	…	…	…
Dep 2	Mesolithic	General deposit	Charred bone	6,160 ± 40	5220–5000	Beta-366711
Dep 3	Mesolithic	General deposit	…	…	…	…
Dep 4	Mesolithic	General deposit	…	…	…	…
Pit S	Mesolithic	S pit	Charred bone	6,290 ± 40	5320–5210	Beta-366709
Pit N1	Mesolithic	N pit, upper part	…	…	…	…
Pit N2	Mesolithic	N pit, lower part	Charred bone	6,650 ± 40	5640–5510	Beta-366710

Note. Radiocarbon estimations from Loteshwar were provided by the Centro Nacional de Aceleradores, Sevilla, Spain. Radicarbon estimations from Vaharvo Timbo were provided by Beta Analytics. ID, identification; N, north; NE, northeast; NW, northwest; S, south; SE, southeast.

Table 2. Grinding stones analyzed in this study

Site and ID	Description	Context
Loteshwar:		
GS 1a	Fragment of bifacial discoidal/lens handstone, face a	Dep 1
GS 1b	Fragment of bifacial discoidal/lens handstone, face b	Dep 1
GS 2a	Half bifacial ovate/oval handstone, face a	Dep 1
GS 2b	Half bifacial ovate/oval handstone, face b	Dep 1
GS 3a	Fragment of bifacial handstone, face a	Dep 1
GS 3b	Fragment of bifacial handstone, face b	Dep 1
GS 4	Fragment of basin grinding slab	Pit 1
GS 5	Fragment of saddle-shaped grinding slab	Dep 3
GS 6a	Broken handstone, used as grinding slab	Pit 3
GS 6b	Unifacial ovate handstone	Pit 3
GS 7a	Half basin grinding slab, face a (not used?)	Dep 2
GS 7b	Half basin grinding slab, face b	Dep 2
GS 8	Half basin grinding slab	Dep 2
GS 9	Half bifacial ovate/oval handstone	Dep 2
GS 10	Half unifacial rectilinear handstone	Dep 2
GS 11	Half unifacial ovate handstone	Dep 3
GS 12a	Fragment of bifacial rectilinear/flat handstone, face a	Dep 3
GS 12b	Fragment of bifacial rectilinear/flat handstone, face b	Dep 3
GS 13	Fragment of basin grinding slab	Dep 3
Vaharvo Timbo:		
GS 1	Fragment of basin grinding slab	Dep 1
GS 2	Fragment of unifacial rectilinear handstone	Dep 1
GS 3	Fragment of basin grinding slab	Dep 1
GS 4	Fragment of basin grinding slab	Dep 1
GS 5	Half unifacial ovate handstone	Dep 1
GS 6	Fragment of basin grinding slab	Dep 2
GS 7	Fragment of basin grinding slab	Dep 2
GS 8	Fragment of basin grinding slab	Dep 1
GS 9	Fragment of unifacial rectilinear handstone	Dep 2
GS 10	Fragment of unifacial rectilinear handstone	Dep 2
GS 11	Fragment of basin grinding slab	Dep 2
GS 12	Fragment of basin grinding slab	Dep 2
GS 13	Fragment of unifacial rectilinear handstone	Dep 2
GS 14	Fragment of unifacial rectilinear handstone	Dep 3
GS 15	Unifacial discoidal handstone	Dep 3
GS 16a	Fragment of unifacial rectilinear handstone, fragment a	Dep 3
GS 16b	Fragment of unifacial rectilinear handstone, fragment b	Dep 3
GS 17	Fragment of basin grinding slab	Dep 3
GS 18	Fragment of basin grinding slab	Dep 4
GS 19	Fragment of unifacial rectilinear handstone	Dep 4

Note. Descriptive terms after Wright (1992). ID, identification.

tolith concentration was calculated per gram of acid insoluble fraction, according to Albert and Weiner (2001), whereas starch concentration was calculated per gram of processed sediment. Phytoliths were described using the International Code for Phytoliths Nomenclature (Madella, Alexandre, and Ball 2005) and starch grains according to the International Code for Starch Nomenclature (ICSN 2011). Taxonomical identification of all plant remains relied on the plant reference collection of the BioGeoPal Laboratory (Complexity and Socio-Ecological Dynamics Research Group, Barcelona) and seed atlases (Cappers and Bekker 2013; Cappers, Neef, and Bekker 2009; Neef, Cappers, and Bekker 2012). Soil pH was measured using a Combo pH and EC HI98129 by Hanna instruments to understand how soil acidity/alkalinity might have affected the preservation of plant remains.

Results

Loteshwar

The majority of the recovered macrobotanical remains are from the Anarta contexts (table 3; fig. 2). The assemblage is dominated by charred caryopses of small millets, mostly *Setaria verticillata* (bristly foxtail) and *Setaria pumila* (yellow foxtail), including one hulled grain of yellow foxtail. Other taxa include cf. *Panicum sumatrense* (little millet), *Brachiaria ramosa* (browntop millet), *Digitaria* sp., and *Echinochloa* cf. *colona* (jungle rice). Because of their poor preservation, several grains were identified only at *Setaria*, *Echinochloa*, and *Brachiaria* (SEB) group level or simply as undetermined small millets. Small millet inflorescences were also preserved mineralized, including *B. ramosa*, *P. sumatrense*, and SEB type. A

Table 3. Results of the macrobotanical analyses from Loteshwar and Vaharvo Timbo

	Loteshwar						Vaharvo Timbo			
Context	Dep 1	Dep 2	Dep 3	Pit 1	Pit 3	Ash 2	Dep 1	Dep 2	Dep 3	Dep 4
Sediment volume (L)	240	75	50	135	160	80	80	60	140	100
Aizoaceae:										
Trianthema portulacastrum	6	…	…	2	…	2	…	…	…	…
Trianthema triquetra	2	…	…	…	…	…	…	…	…	…
Amaranthaceae:										
Chenopodium sp.	11	1	…	1	16	18	…	…	…	…
Cyperaceae	9	1	2	10	5	2	…	…	…	…
Fabaceae:										
Macrotyloma uniflorum	…	…	…	…	…	1	…	…	…	…
Papaveraceae:										
Papaver sp.	1	…	…	1	1	1	…	…	…	…
Pedaliaceae:										
Sesamum indicum	…	…	…	32	…	…	…	…	…	…
Sesamum cf. *malabaricum*	…	…	…	…	…	…	2	…	…	…
Poaceae:										
Chloridoideae:										
Dactyloctenium aegyptium caryopsis	3	1	…	…	1	2	…	…	…	…
cf. *D. aegyptium* inflorescence	…	…	…	…	…	…	1	…	…	…
Panicoideae:										
Brachiaria ramosa caryopsis	1	…	…	…	…	…	…	…	…	…
B. ramosa mineralized inflorescence	6	…	1	…	2	…	…	…	…	…
B. ramosa mineralized lemma	2	…	…	…	…	…	…	…	…	…
Coix lacryma-jobi pseudocarp	+	+	+	>1	+	+	…	…	…	…
Digitaria sp. caryopsis	1	…	…	…	…	…	1	…	…	…
Echinochloa cf. *colona* caryopsis	1	…	…	…	…	…	…	…	…	…
cf. *Panicum sumatrense* caryopsis	2	1	…	1	…	4	…	…	…	…
P. sumatrense mineralized lemma	…	…	…	…	…	1	…	…	…	…
Setaria pumila caryopsis	8	…	…	…	1	3	…	…	…	…
S. pumila caryopsis (hulled)	…	…	…	…	…	1	…	…	…	…
Setaria verticillata caryopsis	9	2	…	8	2	10	…	…	…	…
SEB type caryopsis	7	…	…	…	…	7	…	…	…	…
SEB type mineralized inflorescence	3	1	…	1	1	1	…	…	…	…
Small millet undetermined caryopsis	1	1	…	1	2	2	…	…	…	…
Pooideae:										
Triticum cf. *aestivum* caryopsis	…	…	…	1	…	…	…	…	…	…
Triticum sp. glume base	…	…	…	1	…	…	…	…	…	…
Cerealia undetermined caryopsis	…	…	…	…	1	1	…	…	…	…
Poaceae undetermined inflorescence	…	…	…	…	…	…	3	…	…	…
Poaceae undetermined involucre base	…	1	…	…	…	…	…	…	…	…
Poaceae undetermined glume	…	…	…	…	…	…	3	…	…	…
Poaceae undetermined node	…	…	…	…	…	…	4	…	…	…
Poaceae undetermined spikelet base	…	…	…	…	…	…	27	…	…	…
Solanaceae:										
Lycium sp.	…	…	…	…	1	…	…	…	…	…
cf. *Solanum* sp.	4	1	…	4	1	1	…	…	…	…
Parenchyma fragments	+	…	…	+	…	+	…	…	…	…

Note. Plus sign indicates present. SEB, *Setaria*, *Echinochloa*, and *Brachiaria*.

whole pseudocarp and fragments of mineralized *Coix lacryma-jobi* (Job's tears) were also found. Other grass remains included *Dactyloctenium aegyptium* (crowfoot grass) grains, several fragmented grains of C_3 cereals (including free-threshing wheat, identified as *Triticum* cf. *aestivum*, bread wheat), a *Triticum* sp. glume base and the involucre base of an unidentified grass. The macrobotanical assemblage also consisted of *Sesamum indicum* (sesame), *Papaver* sp. (poppy seed), a small *Macrotyloma uniflorum* seed (horsegram), and two taxa from the Solanaceae family: *Lycium* sp. and cf. *Solanum* sp. Finally, several unidentified species of sedges (Cyperaceae), parenchymatic tissue, and weed taxa such as *Trianthema* spp. and *Chenopodium* sp. were also encountered.

Sediment samples had very high phytolith concentrations (table 4) and a total of 154 silica skeletons, some of which showed characteristic threshing marks, as described by Cummings (2007; fig. 3). Among the single cells, grass short cells had an interesting trend: in all Anarta samples, panicoid mor-

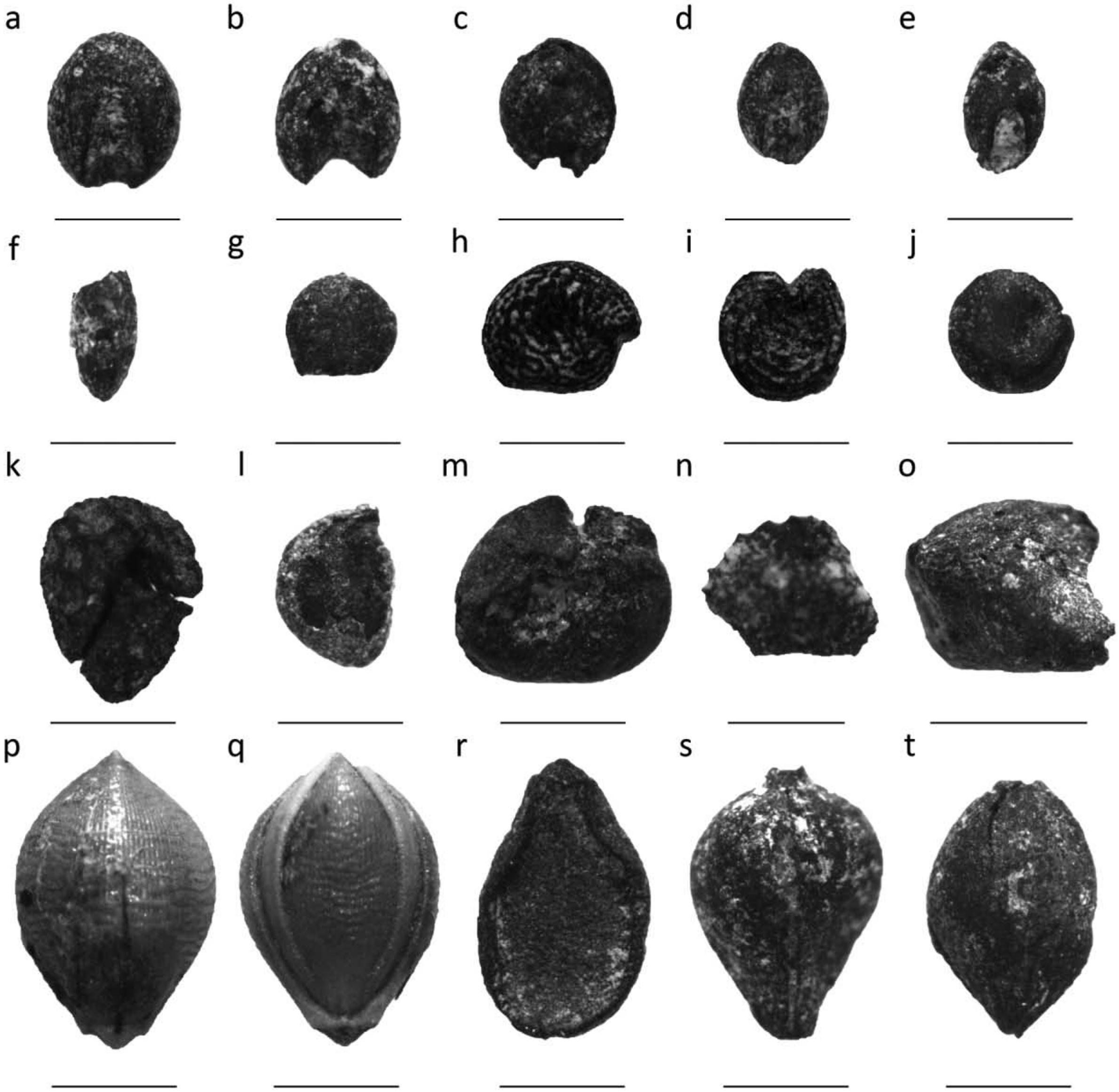

Figure 2. Macrobotanical remains recovered from Loteshwar: *a*, charred *Brachiaria ramosa* caryopsis; *b*, charred *Setaria pumila* caryopsis; *c*, charred *Echinochloa* cf. *colona* caryopsis; *d*, charred *Setaria verticillata* caryopsis; *e*, charred cf. *Panicum sumatrense* caryopsis; *f*, charred *Digitaria* sp. caryopsis; *g*, cf. charred *Solanum* sp. seed; *h*, charred *Trianthema portulacastrum* seed; *i*, charred *Trianthema triquetra* seed; *j*, charred *Chenopodium* sp. seed; *k*, charred *Papaver* sp. seed; *l*, charred *Lycium* sp. seed; *m*, charred *Macrotyloma uniflorum* seed; *n*, charred *Dactyloctenium aegyptium* caryopsis; *o*, half-charred *Triticum* cf. *aestivum* caryopsis; *p*, *q*, dorsal and ventral view of a mineralized inflorescence of *B. ramosa*; *r*, charred *Sesamum indicum* seed; *s*, *t*, charred Cyperaceae seeds. Scale bars = 1 mm (*a–m*, *p–t*), 0.5 mm (*n*), 2 mm (*o*). A color version of this figure is available online.

photypes predominated, whereas samples from the mixed and Mesolithic levels showed more pooids. In all the samples, leaf/culm morphotypes (elongate psilates and sinuates) were the main grass long cells. The single-cell assemblage further included dicotyledon types and tabular scrobiculated cones from sedge achenes. Finally, the assemblage had several undetermined taxa and unidentified phytoliths. The undetermined group includes phytoliths characteristic of several taxa (which cannot be securely assigned to a specific one), and phytoliths whose taxonomical or anatomical origin could not be determined. Unidentified phytoliths are weathered phytoliths without sufficient diagnostic traits for their identification.

Phytolith samples from grinding stones had extremely variable concentrations (table 5). A total of 114 grass silica skeletons were encountered, including eight from panicoid grasses. Only 10 samples—six from Anarta contexts, two from the mixed level, and two from the Mesolithic deposit—had enough phytoliths (>100) to be discussed quantitatively. Leaf/culm morphotypes were again the main grass long cells in all the samples, and the pattern of grass short cell distribution observed in the sediment samples also occurred in the grinding stones.

Starch grains were scarce in sediment samples but abundant in grinding stones (tables 4, 5). There is no difference in the composition of starch assemblages between samples from the various levels. A total of eight morphotypes were identified (fig. 4). The most common typology in all samples was the Panicoideae (Poaceae), divided into three subtypes according to size. Type 1 grains (3–10 μm) are characteristic of small millets, type 3 (>20 μm) occur mostly in big millets, and type 2 (10–20 μm) are found in both groups (Madella, Lancelotti, and García-Granero 2013 and references therein). Six spherical grains found on grinding stones and showing a linear hilum with lines radiating from the centre were attributed to cf. Panicoideae. Starch grains belonging to the Triticeae tribe (Pooideae, Poaceae) were also found: discoidal grains with a smooth surface and lamellae (type A; Yang and Perry 2013), small spherical grains with a smooth surface and a small vacuole (type B; Yang and Perry 2013), and bell-shaped grains with an eccentric, linear hilum. These last two morphotypes can occur in other taxa and were therefore grouped in cf. Triticeae. Other finds include ovoid grains with a smooth surface, lamellae, and a linear hilum diagnostic of the Faboideae (Fabaceae). Six medium-sized (10–20 μm) ovoid grains with a smooth surface, a regular extinction cross and an eccentric small hilum, and one very large (>50 μm) triprismatic grain with a smooth surface, lamellae and a highly eccentric linear hilum could not be assigned to any specific taxonomic group, but their morphology suggests an origin from underground storage organs (rhizomes/tubers). Finally, 61 starch grains could not be identified because of severe damage. Soil pH values were slightly alkaline throughout the sequence (table 4), particularly in samples pit 3, dep 2, and dep 3.

Vaharvo Timbo

Macrobotanical remains were recovered from only the upper layer of the archaeological sequence (table 3; fig. 5) and included two morphologically wild *Sesamum* sp. grains (tentatively identified as *Sesamum* cf. *malabaricum*), one *Digitaria* sp. grain, and one cf. *Dactyloctenium aegyptium* inflorescence. Additionally, several unidentified grass inflorescences, glumes, nodes, and spikelet bases were recovered.

Phytoliths were very scarce in both sediment samples and grinding stones (tables 4, 6). Among sediment samples, only one had enough phytoliths for quantitative analysis (dep 1), with the majority of morphotypes from grass leaf/culm and a few from grass inflorescence (table 4). Moreover, two grass silica skeletons were found, one from an inflorescence and one from a leaf/culm. It is worth highlighting the presence of one small (ca. 10 μm) globular echinate, characteristic of palms (Arecaceae).

Of the 20 grinding stones samples, only four could be discussed quantitatively (<20 phytoliths were encountered on the remaining samples; table 6). Ten grass silica skeletons were encountered, including one from a panicoid grass. Leaf/culm grass long cells predominated, and short cells showed a relatively equal distribution among grass subfamilies. Palm phytoliths as well as one possibly originating from a sedge achene were also observed, while dicotyledonous plants were marginally represented.

The starch assemblage from sediments and grinding stones (183 grains; tables 4, 6) was clearly dominated by type 2/3 Panicoideae grains, with a minor presence of Triticeae, Faboideae, tubers, and one very large (>50 μm) ovoid grain with lamellae and a highly eccentric small hilum (fig. 5) attributed to *Solanum tuberosum* (potato). Soil pH values were slightly alkaline and relatively constant throughout the sequence (table 4).

Discussion

Before considering the archaeobotanical assemblages from Loteshwar and Vaharvo Timbo, we discuss the possible effect of taphonomical processes. Subsequently, hunter-gatherer and agropastoral plant exploitation strategies are discussed and a model for mid-Holocene pastoral land use strategy is proposed. Finally, we focus on the case for a center of primary plant domestication in Gujarat.

The Effect of Taphonomy

A series of depositional and postdepositional processes affected the archaeobotanical assemblages from these sites: (1) the abrasion on phytoliths and starch grains due to grinding, (2) the effect of soil alkalinity and peaks of humidity on phytoliths, (3) the mixing of archaeological deposits belonging to different episodes of the dunes occupation, and (4) the possible contamination during the laboratory processing of the samples.

The effect of grinding on starch grains is well attested experimentally (Henry, Hudson, and Piperno 2009; Yang and Perry 2013). Several starch grains from Loteshwar grinding stones have many characters of damage, including loss of birefringence, fissures in the hilum, swelling, and, occasionally, loss of all diagnostic traits (damaged unidentified grains). Silica skeletons from both sites, having a small number of cells, also suggest mechanical breakage due to milling.

Soil alkalinity facilitates postdepositional chemical dissolution of phytoliths, especially in the presence of water (Madella and Lancelotti 2012; Piperno 2006), such as during the monsoon at Loteshwar and Vaharvo Timbo. Moreover, the consecutive

Table 4. Results of phytolith, starch grain, and soil pH analyses from sediment samples from Loteshwar and Vaharvo Timbo

	Loteshwar								Vaharvo Timbo						
	Dep 1	Dep 2	Dep 3	Pit 1	Pit 2	Pit 3	Ash 1	Ash 2	Dep 1	Dep 2	Dep 3	Dep 4	Pit S	Pit N1	Pit N2
Phytoliths:															
Monocotyledons:															
Arecaceae	…	…	…	…	…	…	…	…	1	–	–	–	…	–	…
Cyperaceae:															
Silica skeletons (leaf)	…	…	…	…	1	…	…	…	…	–	–	–	…	–	…
Single cells (achene)	1	1	…	1	…	2	…	3	…	–	–	–	…	–	…
Poaceae:															
Silica skeletons:															
Inflorescence:															
Panicoideae	…	…	…	1	…	…	…	…	…	–	–	–	…	–	…
Undetermined	2	5	9	6	5	3	5	2	1	–	–	–	…	–	…
Leaf/culm:															
Chloridoideae	…	…	…	…	…	…	…	1	…	–	–	–	…	–	…
Panicoideae	…	…	…	2	2	…	1	…	…	–	–	–	…	–	…
Pooideae	…	…	…	…	1	…	…	…	…	–	–	–	…	–	…
Undetermined	12	5	47	9	10	3	9	7	1	–	–	–	…	–	…
Undetermined	…	1	…	1	…	1	…	1	…	–	–	–	…	–	…
Single cells															
Long cells:															
Inflorescence	21	5	33	6	9	12	8	10	5	–	–	–	…	–	…
Leaf/culm	34	30	100	19	26	38	28	34	42	–	–	–	…	–	1
Undetermined	2	6	8	9	4	6	2	10	3	–	–	–	…	–	…
Bulliform (leaf)	3	9	2	2	1	5	1	2	7	–	–	–	…	–	2
Short cells:															
Chloridoideae	43	51	24	35	40	40	56	69	4	–	–	–	1	–	…

Panicoideae	67	36	14	81	83	58	78	73	7	–	–	–	. . .	–	2
Pooideae	46	54	31	52	55	53	42	46	3	–	–	–	. . .	–	. . .
Undetermined	49	39	25	69	50	57	60	22	6	–	–	–	. . .	–	1
Dicotyledons	7	15	11	. . .	3	1	1	2	. . .	–	–	–	. . .	–	1
Undetermined taxa:															
Silica skeletons	. . .	. . .	. . .	. . .	1	. . .	1	. . .	. . .	–	–	–	. . .	–	. . .
Single cells	33	53	51	23	28	31	22	32	65	–	–	–	3	–	4
Unidentified phytoliths	5	5	16	1	2	. . .	7	8	17	–	–	–	3	–	4
Total silica skeletons	14	11	56	19	20	7	16	11	2	–	–	–	. . .	–	. . .
Total cells in silica seletons	52	34	219	80	71	19	53	48	4	–	–	–	. . .	–	. . .
Total single cells	311	304	315	298	301	303	305	311	160	–	–	–	7	–	15
Phytolith concentration	6.3	.6	.7	12.6	15.1	3.9	23.1	6.8	0	–	–	–	0	–	0
Starch grains:															
Fabaceae:															
Faboideae	. . .	. . .	. . .	1	. . .	. . .	. . .	. . .	. . .	. . .	1	. . .	. . .	. . .	. . .
Poaceae:															
Panicoideae:															
Type 2 (10–20 μm)	. . .	1	1	. . .	. . .	1	1	. . .	1	. . .	. . .	2	3	1	1
Type 3 (>20 μm)	. . .	. . .	1	. . .	. . .	2	1	. . .	. . .	. . .	. . .	. . .	1	. . .	. . .
Pooideae:															
Triticeae	. . .	. . .	1	. . .	2	. . .	1	. . .	. . .	1	1	. . .	. . .	1	. . .
cf. Triticeae spherical	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	2
cf. Triticeae bell shaped	. . .	. . .	. . .	. . .	2	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Solanaceae:															
Solanum tuberosum	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	1	. . .
Tuber undetermined 1	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	1	. . .	. . .	. . .
Undetermined	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	2	. . .	. . .	. . .	. . .	. . .
Damaged unidentified	. . .	1	. . .	. . .	1	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Total starch grains	. . .	2	3	1	5	3	3	. . .	1	3	2	3	4	3	3
Starch concentration	. . .	5	8	2	13	7	7	. . .	3	7	5	7	11	7	7
Soil pH	8.38	8.88	8.88	8.25	8.42	8.88	8.32	8.34	8.44	8.39	8.41	8.70	8.57	8.29	8.60

Note. Minus indicates sample not analyzed. Phytolith concentration is expressed in millions per gram of acid insoluble fraction. Starch concentration is expressed in grains per gram of original sediment.

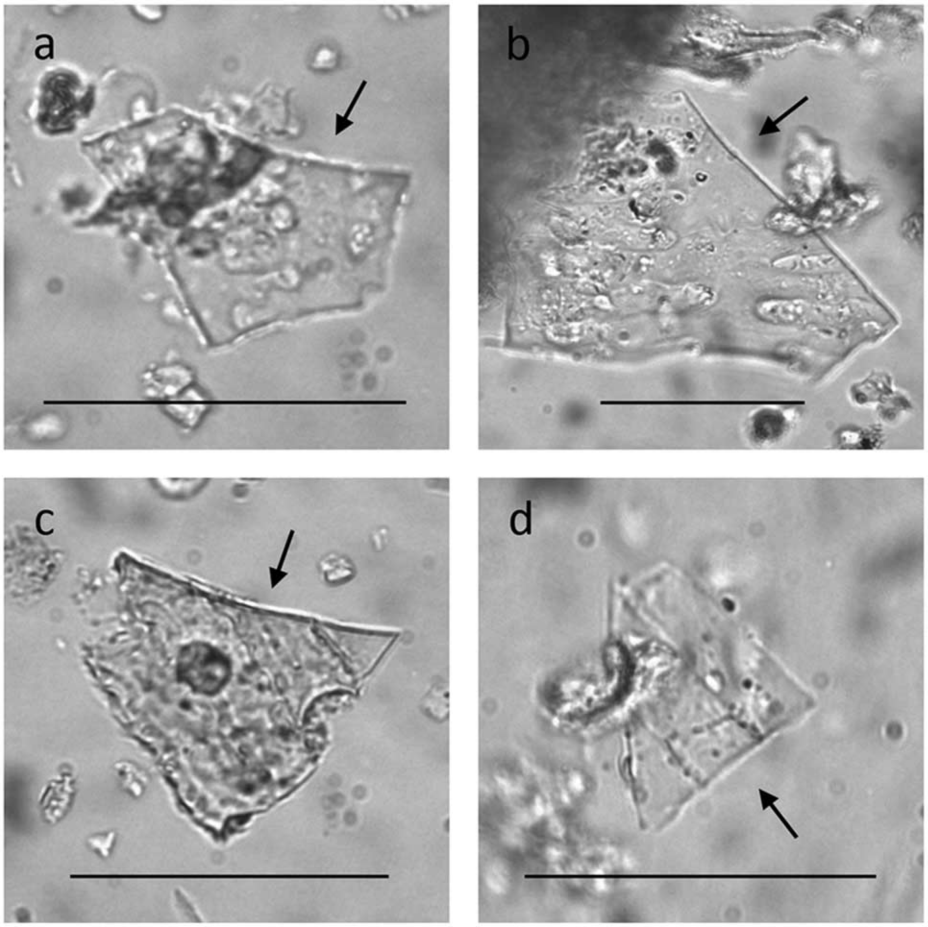

Figure 3. Silica skeletons with potential threshing sledge marks (arrows) recovered from Loteshwar: *a*, *Panicum/Setaria*-type inflorescence; *b*, *Echinochloa*-type inflorescence; *c*, *d*, Poaceae leaf/culm. Scale bars = 50 μm. A color version of this figure is available online.

occupational episodes at Loteshwar (the initial hunter-gatherer occupation and the excavation of pits during the Anarta period) resulted in the formation of a stratum with Chalcolithic and Mesolithic material (mixed level).

The presence of a potato starch grain in one sample from Vaharvo Timbo suggests contamination. The purportedly powder-free gloves used in Vaharvo extractions tested positive in laboratory checks for possible corn (type 2/3 Panicoideae grains), which is the most common source of commercial starch (Crowther et al. 2014). Since the whole residues were processed, we were not able to repeat the extractions. Thus, we do not further discuss the starch samples from Vaharvo Timbo in this work.

In Loteshwar extractions, we used a different brand of gloves, which tested negative for starch contamination, as did other control samples from laboratory supplies (García-Graneroet al. 2016). Nonetheless, the presence of Triticeae starch grains in Mesolithic Loteshwar is surprising. This grass tribe includes major cereals, such as wheat and barley, that were introduced in North Gujarat from the Indus Valley during the Urban Harappan period (ca. 2500 BC) or possibly earlier, at the end of the fourth millennium BC (Pokharia et al. 2011). The grains (representing only 0.96% of the total) might therefore be related to local grass species producing starch similar to wheat/barley (Yang and Perry 2013). Pooid grasses are very rare in this region today (Parmar et al. 2012), but the high concentration of Pooideae-type phytoliths in Mesolithic deposits seems to suggest a wider presence during the early-mid Holocene (see below).

Hunter-Gatherers Plant Exploitation during the Early-Mid Holocene

Paleoclimatic models show a slow but constant weakening of the Indian summer monsoon after the early Holocene wet phase, ca. 10,000–7,000 years ago, with a certain degree of variability at regional level (Gasse et al. 1996; Gupta et al. 2006; Hu et al. 2008; Liu et al. 2003; Overpeck et al. 1996; Wei and Gasse 1999). Preliminary data from interdunal depressions in the vicinity of Loteshwar and Vaharvo Timbo suggest that perennial water bodies existed until ca. 7,000 years ago (NoGAP, unpublished data), contrary to present-day conditions where most depressions dry up during the winter (Conesa et al. 2014).

The similar temporal and ecological ranges, together with comparable lithic assemblages (Gadekar et al. 2014; C. Gadekar, personal communication), suggest that the sites were frequented by groups of hunter-gatherers with similar economic strategies. The archaeobotanical record from Vaharvo Timbo is poor, but the presence of *Digitaria* sp., *Dactyloctenium aegytium*, and spikelet bases from at least four different species suggests gathering of wild grasses. Palm and sedge phytoliths indicate the possible exploitation of wild palms (e.g., *Phoenix sylvestris*; Barh and Mazumdar 2008; Davis and Johnson 1987; de Zoysa 1992; Khare 2007; Pandey et al. 2007) and of other plants from the more humid interdunal areas. Genetic evidence indicates that sesame was domesticated in South Asia (Bedigian 2003), but the exact center of domestication is unknown, and the recovery of wild sesame seeds highlights the presence of this plant in North Gujarat from the early-mid Holocene.

The archaeobotanical evidence from Mesolithic Loteshwar shows a high presence of dicot phytoliths, suggesting that hunter-gatherers exploited woody plants more than agropastoral people. It is also interesting to note the relatively high presence of pooid morphotypes, mainly rondels. Previous paleoecological research in Gujarat suggests phases of higher winter precipitation during the Holocene (Prasad, Phartiyal, and Sharma 2007; Singh, Prasad, and Chakraborty 2007), which might have facilitated a higher presence of pooid grasses. The pooid morphotypes, however, may also derive from a so far unidentified rondel-producing panicoid grass, as in other areas of the world (e.g., *Panicum turgidum* in West Africa; Radomski and Neumann 2011: table 3). Indeed, several species of Panicoideae were exploited in Mesolithic Loteshwar, as suggested by starch grains from this group. The starch assemblage also indicates the exploitation of wild pulses.

Overall, the archaeobotanical evidence from Mesolithic Loteshar and Vaharvo Timbo suggests the exploitation of a wide range of plants originating from (semi)permanent water bodies, creating marshy microenvironments in the dune-interdune area. When combined with the zooarchaeological analysis from Loteshwar (Patel 2009), these data show that hunter-gatherers inhabiting the semiarid North Gujarat during the early-mid Holocene were relying on a broad-spectrum economy.

Millet Cultivation and Seminomadic Pastoralism: A Model of Adaptive Strategy

The boundary between food procurement (plant gathering) and food production (plant cultivation) has been drawn at the human intentionality to disrupt the life cycle of a plant population to encourage growth (Ford 1985:2; Harris 1996:446). The intentional cultivation of plant populations might or might not end in a domestication event, and in any case, the appearance of domestic traits would be delayed by at least 1,000–2,000 years (Fuller and Allaby 2009). Despite the lack of domestic traits in archaeobotanical remains, the human intervention in a plant life cycle can be identified in the archaeological record through the analysis of cultivation-related artifacts (e.g., hoes) or the presence of weeds in the plant assemblage (Jones 1992).

The integration of our archaeobotanical data and earlier research is the basis for a model of mid-Holocene agropastoral land use strategy in North Gujarat (fig. 6) by a seminomadic group with a low-level food producing economy (Smith 2001). The current regime of interdunal water availability was established ca. 7,000 years ago, and the human population had to adapt to new ecological settings, with reduced humidity and interdunal water bodies during the premonsoon season (Conesa et al. 2014). Zooarchaeological data advocate for the adoption of seminomadic pastoralism (sensu Khazanov 1984:19) from neighboring herders (Fuller 2006) or as a locally developed process of cattle domestication (Patel 2009). Plant remains from Anarta Loteshwar suggest that livestock was complemented with cultivation of local small millets and probably other *kharif* crops, such as Job's tears, horsegram, and sesame. The presence of weeds associated with cultivation (*Trianthema* spp. and *Chenopodium* sp.) supports the idea that these plants were not simply gathered as wild.

The integration of millet cultivation and seminomadic pastoralism has been (and still is) a successful subsistence strategy for populations in semiarid regions worldwide, including, for instance, the Central Eurasian steppes during the Final Bronze Age and the Early Iron Age (Chang et al. 2003; Lightfoot et al. 2014; Murphy et al. 2013; Svyatko et al. 2013) and present-day FulBe groups in the Sahel (Thébaud and Batterbury 2001). The cultivation of fast-maturing small millets, harvested 60–90 days after sowing (Weber and Fuller 2008), is compatible with the seasonal migration cycles of mobile pastoral groups, enabling them to take advantage of several ecological niches (Di Cosmo 1994). Seminomadic agropastoral groups inhabiting North Gujarat during the mid-Holocene would have scheduled plant-related activities according to the highly seasonal monsoon regime, maximizing mobility during periods of scarce resource availability.

Monsoon (June-September). Pastoral groups sowed small millets and other *kharif* crops in the more fertile interdunal depressions (soils with higher humidity and clay) with the first monsoon rains (between June and July; fig. 6*a*), and a certain degree of land clearance was probably part of the presowing land preparation (cf. Singh 2010). During the period of crop growth and maturation (August-September), these groups would dwell in the area, feeding cattle on the green open scrublands and gathering plants from the marshy areas. Some degree of crop weeding might have occurred, although small millets do not need much work investment (Fogg 1983; Kimata, Ashok, and Seetharam 2000; Weber and Fuller 2008). The presence of big millet starch grains (Panicoideae type 3) and

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

	GS_1a	GS_1b	GS_2a	GS_2b	GS_3a	GS_3b	GS_4	GS_5	GS_6a	GS_6b	GS_7a	GS_7b	GS_8	GS_9	GS_10	GS_11	GS_12a	GS_12b	GS_13
Phytoliths:																			
Monocotyledons:																			
Cyperaceae (achene)	1	...	...	...	...	...	1	1	...	...	...	3	...	...	...	...	...	...	...
Poaceae:																			
Silica skeletons:																			
Inflorescence:																			
Panicoideae	2	...	1	...	...	...	1	...	...	...	1	...	...	...	...	...	...	...	...
Undetermined	4	...	2	...	...	...	1	1	...	...	...	...	...	...	...	...	...	...	...
Leaf/culm:																			
Panicoideae					1		2	...	...	...	...	...	...	...	...	...	...	...	...
Undetermined	2	1	5	...	29	37	6	1	...	1	...	3	...	...	...	2	...	...	...
Undetermined:	1	...	2	...	4	2	1	...	...	...	...	1	...	...	...	...	...	...	...
Single cells																			
Long cells:																			
Inflorescence	6	5	2	1	11	5	10	6	...	3	1	13	4	2	...	...	...	...	...
Leaf/culm	43	17	34	...	51	47	34	30	...	9	1	50	22	...	...	34	...	...	...
Undetermined	8	1	8	...	1	0	14	15	...	...	...	13	22	...	...	10	...	...	...
Bulliform (leaf)	7	4	3	...	8	18	2	7	...	1	...	4	15	...	...	16	...	...	...
Short cells:																			
Chloridoideae	19	41	54	...	42	24	29	27	...	...	...	32	12	2	...	12	...	...	...
Panicoideae	71	32	64	...	49	45	65	33	...	2	...	43	38	3	...	6	...	...	...
Pooideae	54	28	49	...	35	48	61	39	...	...	...	33	50	1	...	19	...	...	...
Undetermined	34	15	35	...	30	36	37	14	...	...	...	30	15	...	...	5	...	...	...
Dycotyledons	3	2	5	...	...	...	7	23	...	...	...	15	35	2	...	25	...	...	...
Undetermined taxa	54	58	46	1	73	79	38	107	1	3	...	65	90	7	1	173	...	...	...
Unidentified phytoliths	8	12	3	...	12	13	3	8	1	2	...	43	7	2	...	19	...	...	...
Total silica skeletons	9	1	10	...	34	39	11	2	...	1	1	4	...	...	...	2	...	...	...

Total cells in silica skeletons	57	5	24	...	153	243	49	6	...	10	2	12	...	...	...	5	...	...	...
Total single cells	308	215	303	2	312	315	301	310	2	20	2	344	310	19	1	319	...	...	...
Phytolith concentration	3.6	.1	2.4	0	.2	.1	8.1	.5	0	0	0	1.1	.4	0	0	0	0	0	0
Starch grains:																			
Fabaceae:																			
Faboideae	7	1	11	5	4	5	3	7	5	2	3	10	5	6	12	9	24	8	4
Poaceae:																			
Panicoideae:																			
Type 1 (<10 μm)	8	13	...	...	...	...	1	...	...	2	...	...	...	39	67	5	198	9	1
Type 2 (10–20 μm)	1	1	2	4	2	3	4	4	3	4	2	2	3	1	23	4	2	4	6
Type 3 (>20 μm)	4	1	1	1	1	...	...	...	2	2	...	2	...	...	1	...	1	2	...
cf. Panicoideae	...	...	...	...	...	1	...	...	...	...	...	...	1	1	2	...	1	...	...
Pooideae:																			
Triticeae	...	...	...	...	...	...	1	...	2	...	...	...	...	4	...	...	...	...	2
cf. Triticeae spherical	...	1	...	1	...	...	6	...	2	1	1	...	...	...	1	...	2	...	...
Tuber undetermined 1	...	1	...	...	...	...	...	1	1	...	1	1	...	...	...	...	1	...	...
Tuber undetermined 2	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...
Damaged unidentified	7	18	1	...	1	2	6	2	3	1	...	2	...	3	1	5	1	4	2
Total starch grains	27	36	15	11	8	11	21	14	19	12	7	17	9	54	107	23	230	27	15
Starch concentration	4.4	8.3	3.7	4.9	3.4	5.2	2.7	1.5	5.9	3.9	.4	2.1	1.6	6.5	19.4	.9	52.4	5.7	1.5

Note. Phytolith concentration is expressed in millions per gram of acid insoluble fraction. Starch grain concentration is expressed in thousands per gram of original sediment.

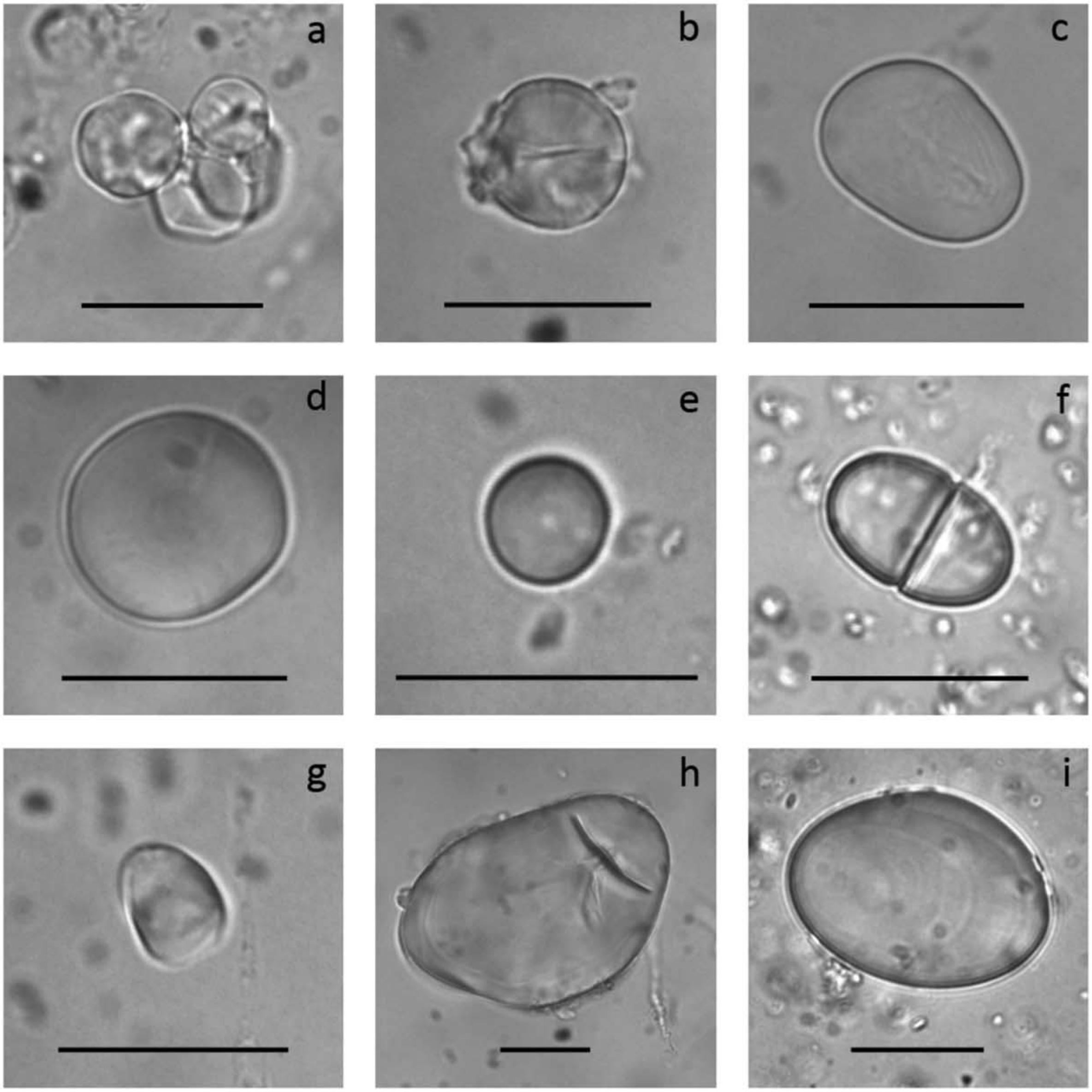

Figure 4. Starch grains recovered from Loteshwar and Vaharvo Timbo: *a*, Panicoideae type 1/2 grains; *b*, cf. Panicoideae grain; *c*, Faboideae grain; *d*, Triticeae grain; *e*, cf. Triticeae (spherical) grain; *f*, cf. Triticeae (bell-shaped) grain; *g*, tuber undetermined 1 grain; *h*, tuber undetermined 2 grain; *i*, *Solanum tuberosum* grain. Scale bars = 20 μm. A color version of this figure is available online.

pseudocarps of Job's tears suggest the possibility of a mixed cultivation strategy. Job's tears, originating in Southeast Asia, became ubiquitous in Gujarat and Rajasthan during the midlate Holocene; it was mostly used as ornaments, but it probably also had some role in people's diet (García-Granero, Lancelotti, and Madella 2015; Pokharia et al. 2011 and references therein). Fast-maturing sesame, grown for its high oil content, could have been cultivated in mixed stands with pulses, similarly to current traditional agriculture in Kachchh (Singh 2010). *Sesamum indicum* was well established as a *kharif* crop during the Urban Harappan phase (ca. 2500–1900 BC) of the Indus Valley Civilization (Tengberg 1999), from where it spread to southwest Asia (Bedigian 2004; Fuller 2003).

Postmonsoon (October-January). Between October and November, crops would be harvested (fig. 6*b*). Because of different inter- and intraspecies maturation rates, plants were probably harvested on multiple episodes (Fogg 1983; Kimata, Ashok, and Seetharam 2000; Weber and Fuller 2008), and millets as immature spikelets to avoid major seed loss (Fuller and Allaby

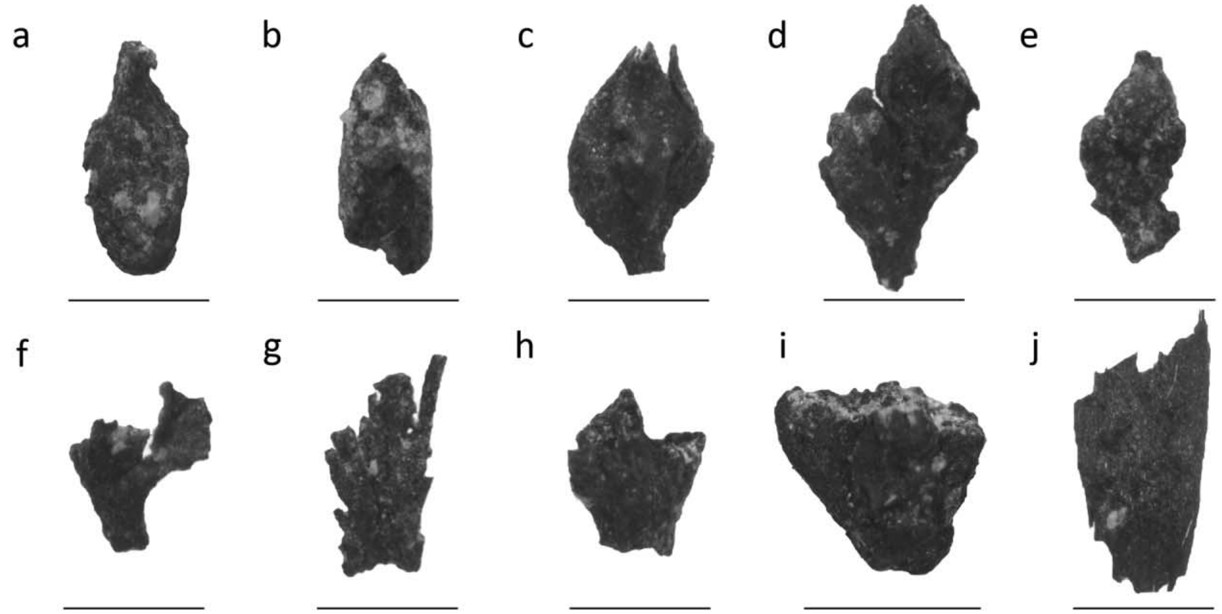

Figure 5. Macrobotanical remains recovered from Vaharvo Timbo: *a*, charred *Sesamum* cf. *malabaricum* seed; *b*, charred *Digitaria* sp. caryopsis; *c*, charred cf. *Dactyloctenium aegyptium* inflorescence; *d*, *e*, charred Poaceae inflorescences; *f–i*, Poaceae spikelet bases; *j*, Poaceae glume. Scale bars = 1 mm (*a–h*, *j*), 2 mm (*i*). A color version of this figure is available online.

2009). Inflorescence structure in small millet species can sometime be loose, requiring a cutting at the base of the plants that results in the incorporation of a large quantity of weeds and the need for labor-intensive crop processing (Reddy 1997). During postharvest (December-January; fig. 6*c*), cattle would be fed on leaves/culms leftovers. Grass fodder was probably important throughout the year, as highlighted by the isotopic analyses from domestic cattle remains at Loteshwar (B. Chase, personal communication). Part of the grains would have been preserved for next year sowing, and plant macroremains (weeds of similar size as small millets and mineralized inflorescences) suggest that small millets were stored hulled, probably to protect them (Bouby, Fages, and Treffort 2005; Reddy 1997). Millet grains can be stored for up to 3 years (Weber and Fuller 2008), but a technological study of one of the Anarta pits uncovered at Loteshwar in 2009 highlights that the storage structures were used only during the dry season (lack of waterproofing by plastering; Balbo et al. 2015), thus indicating that crops were not likely to be stored for long periods and probably mostly set aside during the months following the harvest. Final crop processing (dehusking and grinding) was most likely carried out on a daily basis on site, as suggested by the microbotanical evidence from grinding stones.

During years of scarce yields, wild grasses could have supplemented the cultivated grains. The presence of crowfoot grass in the macrobotanical assemblage suggests such a possibility, and it would also explain the relatively high presence of saddle phytoliths in sediments and grinding stones. This plant is widely distributed throughout the tropics, subtropics, and warm temperate regions of the Old World (Manidool 1992), and it is generally considered a weed. Ethnographic record from modern Rajasthan illustrates that it can be consumed as a famine crop alone, mixed with semiground pulses to prepare Keech, or ground with millet for breadmaking (www.hort.purdue.edu).

Premonsoon (February-May). During the summer months (February-May), the gathering of other plant resources such as sedges and tubers would have increased to complement the dwindling grains (fig. 6*d*). Macrobotanical and phytolith evidence at Loteshwar suggests the use of sedges, possibly also for consumption, collected from the marshy interdunal depressions. Moreover, carbonized parenchymatic tissue and starch grains indicate the consumption of tubers. Plant remains from Urban Harappan Shikarpur in Kachchh (García-Granero, Lancelotti, and Madella 2015) and several Neolithic sites in southern India (Fuller et al. 2004) imply a more important role than previously acknowledged of tuberous plants in the prehistory of the subcontinent. To overcome premonsoon scarcity, seminomadic groups in North Gujarat could have also traded with neighboring Harappan communities, and the minor presence of wheat (a winter crop) at Loteshwar can be interpreted as such. Further evidence for contacts—in this case, outside the Indus Valley—was highlighted by the presence of *Musa* sp. phytoliths in a previous study from Loteshwar (García-Granero 2011; García-Granero et al., forthcoming). With the arrival of the monsoon, the interdunes would have been sown again, with the option of exploiting the same depressions for a few years

Table 6. Results of phytolith and starch grain analyses from grinding stones from Vaharvo Timbo

	GS1	GS2	GS3	GS4	GS5	GS6	GS7	GS8	GS9	GS10	GS11	GS12	GS13	GS14	GS15	GS16a	GS16b	GS17	GS18	GS19
Phytoliths:																				
Monocotyledons																				
Arecaceae	1	...	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Cyperaceae (achene)	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Poaceae:																				
Silica skeletons:																				
Leaf/culm:																				
Panicoideae	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...
Undetermined	...	4	...	4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Undetermined	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Single cells																				
Long cells:																				
Inflorescence	5	3	6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Leaf/culm	46	49	48	23	...	3	2	...	...	...	...	3	1	...	...	...	...	...	...	...
Undetermined	8	5	7	3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Bulliform (leaf)	4	5	31	7	...	...	2	...	...	...	...	1	...	...	...	...	...	...	...	...
Short cells:																				
Chloridoideae	17	12	24	12	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1
Panicoideae	17	17	16	19	...	2	2	...	...	...	1	...	2	...	1	...	...	...	...	...
Pooideae	25	20	17	5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Undetermined	17	4	9	4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Dycotyledons	7	5	...	1	1	...	...	...	1	...	...	...	1	...	...	...	...	...	...	...
Undetermined taxa	102	180	143	76	...	9	9	...	3	...	1	7	1	...	...	...	1	7	1	3
Unidentified phytoliths	97	67	49	31	...	3	1	...	1	...	...	4	1	...	...	...	...	2	...	...
Total silica skeletons	1	4	...	4	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...
Total cells in silica skeletons	4	14	...	12	...	...	...	...	...	...	...	...	...	...	10	...	...	...	...	...
Total single cells	346	367	353	181	1	18	16	...	5	...	2	15	6	...	1	...	1	9	1	4
Phytolith concentration	35	12	5	8	0	1	1	0	.5	0	.4	2	.3	0	1	0	.4	1	.2	.3
Starch grains:																				
Fabaceae:																				
Faboideae	...	...	2	...	...	1	...	1	...	1	...	...	1	...	...	...	...	...	...	1
Poaceae:																				
Panicoideae:																				
Type 2 (10–20 μm)	1	5	1	3	3	20	1	6	2	6	3	5	8	12	5	3	1	12	...	2
Type 3 (>20 μm)	...	1	...	...	3	5	1	3	...	1	1	3	7	2	1	5	...	2	...	1
Pooideae:																				
Triticeae	...	...	1	...	1	3	1	...	1	...	...	...	...	...	...	...	1	1	...	...
cf. Triticeae spherical	...	...	...	...	...	...	...	...	6	...	...	...	...	...	...	...	...	...	...	...
Undetermined	...	...	...	...	...	2	...	...	...	...	...	...	...	1	...	1	...	...	...	...
Damaged unidentified	1	1	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Total starch grains	2	7	4	4	7	31	3	10	9	8	4	8	16	15	6	9	2	15	...	4
Starch concentration	66	196	63	102	576	2,163	168	661	685	368	366	349	821	640	260	948	196	1,512	...	155

Note. Phytolith concentration is expressed in thousands per gram of acid insoluble fraction. Starch concentration is expressed in grains per gram of original sediment.

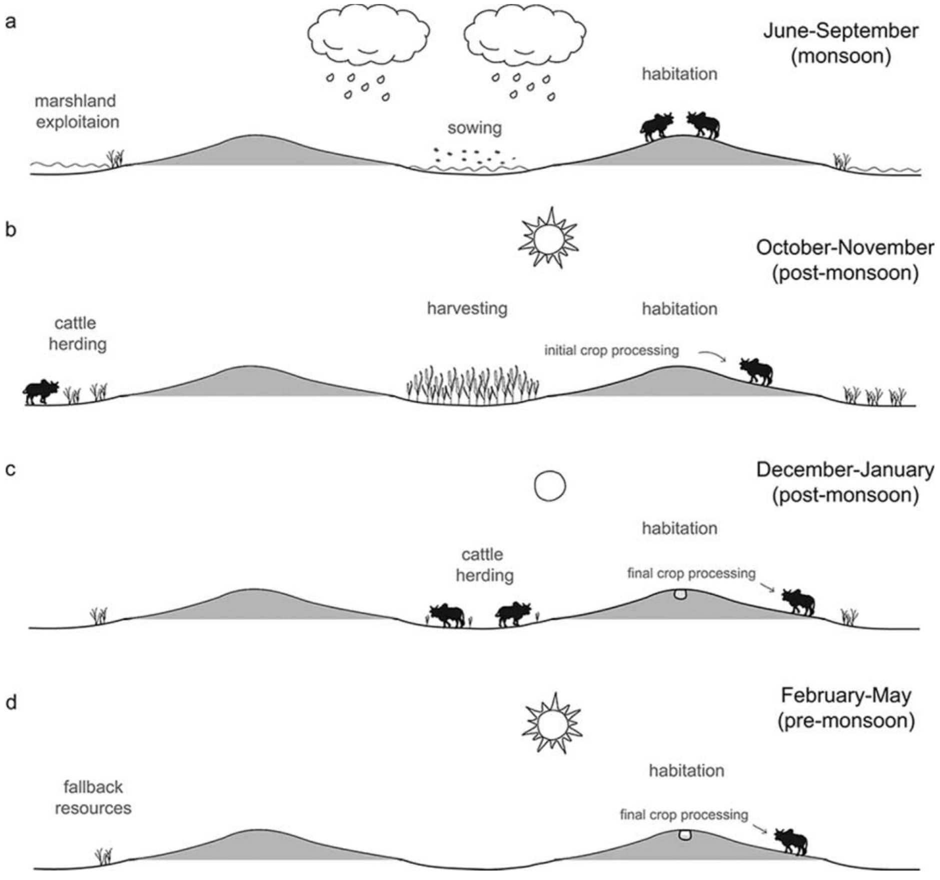

Figure 6. Model of the land use strategy of seminomadic populations in North Gujarat during the mid-Holocene: *a*, monsoon period; *b*, *c*, postmonsoon period; *d*, premonsoon period.

and then moving to nonexploited grounds within the dune-interdune area.

Was North Gujarat a Center of Plant Domestication?

Cultivation of small millets and tropical pulses was well established in Gujarat by the Urban Harappan period (Fuller 2006). The local character of the prehistoric Gujarati crop package suggests the existence of an indigenous plant domestication process (Fuller 2006, 2011; Fuller and Murphy 2014; Purugganan and Fuller 2009). The archaeobotanical evidence from Loteshwar and Vaharvo Timbo reveals a continuous history of plant gathering and then predomestication cultivation of at least three different groups: small millets, pulses, and sesame. The cultivation is unequivocal from the archaeobotanical record, but defining North Gujarat as a primary center of domestication requires an assessment of the domestic character of these plants. Some of the morphological and genetic traits that characterize a plant as domestic are the loss of seed dispersal mechanisms, the loss of germination inhibition, changes in seed size, and the appearance of seasonality control (Fuller and Allaby 2009).

Germination inhibition (loss of seed dormancy) and changes in seed size would occur during predomestication cultivation and should therefore be the first observed archaeobotanically, especially in the case of size change. South Asian small millets do not show an increase in seed size after domestication, and most of them are still found wild or as weeds nowadays (Fuller 2011: table A5). The small millets recovered from Anarta Loteshwar and later Harappan settlements in Gujarat are no exception to this, hindering the possibility of making inferences on their domestication status sensu stricto. A similar case can be made for pulses, which were recovered at Loteshwar from the macro- (horsegram) and microbotanical (Faboideae starch) assemblages, suggesting exploitation since the seventh millennium BC. Tropical pulses are commonly found in Harappan settlements in Gujarat and Rajasthan, and wild stands of *Macrotyloma* and *Vigna radiata* (mung bean) are still present in the region (Fuller and Harvey 2006).

The native character of these plants and their long-term presence (hundreds to thousands of years) in the archaeological records—including the occurrence of other taxa considered associated weeds—all advocate for North Gujarat as a center of small millet and pulses (probably horsegram) domestication. Dating the origins of small millet and horsegram exploitation and cultivation in North Gujarat is, however, difficult because of the challenging archaeological deposits. Indeed, the lack of clear stratigraphy and significant pre- and postdepositional taphonomic processes in most Anarta sites create a scant macrobotanical assemblage. Similar processes of combined small millets and pulses domestication occurred in southern India (Fuller et al. 2004). Horsegram has been cultivated in southern India since ca. 2500 BC (Fuller and Harvey 2006) and small millets from ca. 2000 BC (Fuller 2011), therefore later than the mid third millennium BC Anarta remains from Loteshwar.

The seeds of domestic sesame from Anarta Loteshwar are among the earliest recovered in South Asia (for a review, see Fuller 2003). The presence of wild sesame seeds at Vaharvo Timbo suggests that the plant was already exploited by hunter-gatherer groups during the early-middle Holocene and possibly became locally domesticated during the mid-Holocene. However, further evidence and a more robust chronology are needed to establish North Gujarat as the center of sesame domestication.

Conclusions

The archaeobotanical data from Loteshwar and Vaharvo Timbo, in the wider context of North Gujarat, are an illustrative example of human adaptation to climatic and environmental changes in semiarid regions. The end of the hunter-gatherer occupation at these sites roughly coincides with the weakening of the precipitations (ca. 7,000 BP) and the retreat of the interdune marshland environments. This evidence suggests that food production emerged in North Gujarat as a response to weakening rains (monsoon) to ensure resource predictability, as it seems to have been the case in other semiarid areas of the world, such as the African Sahel (Marshall and Hildebrand 2002). In our area, human populations adopted a strategy that involved seminomadic pastoralism, the cultivation of fast-maturing crops, and the gathering of wild plants. We consider that our data support a local origin of plant domestication and that North Gujarat can be seen as a primary center of origin, regardless of a local development of animal domestication (Patel 2009) or through adoption from neighboring areas such as the southern Indus Valley (Fuller 2006).

Acknowledgments

Fieldwork at Loteshwar and Vaharvo Timbo was funded by the Spanish Ministry of Education, Culture, and Sport (Programa de Ayudas para Proyectos Arqueológicos en el Exterior 2009 and 2011) and the Catalan Government (Programa EXCAVA 2009). Laboratory work was funded by the Spanish Ministry of Economy and Competitiveness (Programa I+D, HAR2010-16052). We are grateful to the members of the North Gujarat Archaeological Project for their help during the fieldwork and for discussion, to G. Orlando (Università degli Studi di Salerno) for his assistance during the sorting of flotation samples, to the Archaeological Survey of India for granting excavation permissions, and to the Maharaja Sayajirao University of Baroda. J. J. García-Granero acknowledges funding from a JAE Predoc doctoral research grant (Spanish National Research Council and European Social Fund). Finally, we would like to acknowledge the comments of several anonymous reviewers as well as M. Aldenderfer, who helped to improve the original manuscript. CaSEs is a Grup de Recerca Emergent de la Generalitat de Catalunya (SGRe 1417).

Comments

Alison Crowther
School of Social Science, Michie Building, University of Queensland, Brisbane, Queensland 4072, Australia (a.crowther@uq.edu.au). 24 IX 15

Even though it is now recognized that there are at least 19 independent centers of agricultural origins worldwide (Larson et al. 2014), hard data in the form of archaeological plant remains have been slow in forthcoming for many, particularly in Africa and South Asia. Consequently, our ability to formulate and refine regional models of crop origins and subsistence transitions needed for global comparison has been seriously hindered. North Gujarat is one of three regions of South Asia proposed as one such locus of domestication (Fuller 2006, 2011), yet it is entirely lacking in archaeobotanical evidence for the period spanning the move from food gathering to food production (Murphy and Fuller 2014). García-Granero et al.'s study of early plant use by Mesolithic hunter-gatherers and Chalcolithic pastoralists at two mid-Holocene sites in North Gujarat therefore provides a much needed, archaeobotanically informed view of these processes.

Although the question of whether Gujarat is a center of plant domestication is ultimately left open in their paper, García-Granero et al. build a compelling case for the mid-Holocene transition to cultivation at the site of Loteshwar. This argument is based primarily on the presence of seeds from arable weeds (*Trianthema* and *Chenopodium*; the former a common millet weed in Harappan and later sites; Fuller et al. 2014) alongside the remains of small millets (e.g., *Panicum sumatrense*, *Brachiara ramosa*, and *Setaria* spp.), tropical pulses (*Macrotyloma uniflorum*), and the important oil crop, sesame (*Sesamum indicum*), among others. These findings are congruent with the local distribution of the wild progenitors of these crops as well as archaeobotanical evidence presented elsewhere showing that they were established as key domesticates in Gujarat by the Harappan period (see Fuller and Murphy 2014). The study thus represents a significant breakthrough in the search for agricultural origins in South Asia.

It is now widely accepted that the pathway to agriculture was not necessarily uniform or linear but a dynamic process that followed diverse regional trajectories as hunter-gatherers actively responded to new environmental opportunities and challenges at different times and places. For North Gujarat, García-Granero et al. present a model that situates the earliest phases of cultivation in the context of a weakening Indian summer monsoon system, where hunter-gatherers were compelled to begin cultivating wild plants to ensure a predictable and reliable food supply. As shown by previous zooarchaeological studies, this was broadly concurrent with a shift toward seminomadic pastoralism, with livestock as well as crops such as wheat (*Triticum* sp.) likely acquired through contact with Harappan cultures. This model of agropastoral land use neatly encapsulates the available archaeological and paleoenvironmental data and presents another case globally where local environmental and cultural circumstances lent themselves to the development of cultivation before permanent sedentism.

Undoubtedly crucial to the success of this study was the adoption of an integrated archaeobotanical strategy that employed multiple lines of macro- and microbotanical evidence. This approach has long been used in tropical regions, such as the Americas and Oceania, where early subsistence regimes focused on underground storage organs (roots and tubers) as well as seeds and fruits. However, archaeobotanists working in regions where seed crops dominate—such as the Near East, Africa, East Asia, and South Asia—have been comparatively slow to adopt multiproxy toolkits (though studies are increasing). Yet it is this strategy that gives García-Granero et al.'s approach strength, enabling them not only to offset the preservational biases of different types of plant remains against one another but also to combine multiple data sets to build stronger cases for the presence of particular plants or plant groups at each site.

While an integrated multiproxy methodology enabled the authors to overcome certain biases, a number of other archaeobotanical challenges were also encountered. The stratigraphic mixing of deposits at Loteshwar—which caused Anarta phase macrobotanical remains to intrude into the lower Mesolithic layers—proved particularly problematic for chronological reconstruction. As a result, chronological inferences relating to the Mesolithic phase rely on dates obtained during previous excavations at the site (forming the basis, for example, for the suggested antiquity of pulse exploitation dating to the seventh millennium BC). Yet the stratigraphic relationship between the recovered archaeobotanical assemblages and these previous dates has not been made clear. Given that García-Granero et al.'s radiocarbon dates also suggest a shorter chronology for their Anarta layers compared with the previous excavations, this issue warrants further discussion. The absence of dates from deposit 1 at Mesolithic Vaharvo Timbo—which was the only layer from that site to produce macroremains—also presents chronological limitations. Although the authors acknowledge the need for a "more robust chronology," it seems an oversight to not directly accelerator mass spectrometry date the seed macroremains from these sites, especially as recent advances in radiocarbon pretreatment methods now allow for the improved dating of very small millet-sized seeds (e.g., Motuzaite-Matuzeviciute et al. 2013).

Other taphonomic factors discussed as having possible effects on the archaeobotanical assemblages include the abrasion of microremains during grinding (which, in the case of starches, can also make granules more susceptible to enzymatic decay) and the chemical dissolution of phytoliths. To this list, I would also add the differential preservation of starch granules in sediments versus grindstones, where entrapment in surficial pits may help protect starch from soil-borne starch-degrading enzymes (Barton and Matthews 2006; Haslam 2004). This factor may explain the observed pattern of starch granule abundance in grindstones and scarcity in sediment samples.

Perhaps most striking, however, was the impact of modern starch contamination on their study, which, once realized, prompted the authors to disregard all starch data from Vaharvo Timbo. It appears near impossible at this stage to determine which, if any, of the recovered granules might be genuine ancient starches, particularly as the expected ancient morphotypes overlap with the modern contaminants. The extent of the problem is perhaps signaled by the almost two orders of magnitude greater number of starches recovered from grindstones at Vaharvo Timbo compared with Loteshwar (on average, about 72 times more starches per artefact, on the basis of concentration), with the overwhelming majority of those at Vaharvo Timbo (82%) being the same Panicoideae types as detected on the nonpowdered gloves worn during extraction. These results serve as a warning to analysts of the risks that modern laboratory contaminants can potentially pose in skewing ancient starch data (see also Crowther et al. 2014).

These matters aside, I certainly look forward to seeing the results of future research by this team at these and related sites in North Gujarat. In this regard, there are many avenues that the authors might explore to build on their multiproxy method. For example, the analysis of characteristic use-wear patterns that can develop on grindstones during plant processing would serve as the perfect complement to the starch and phytolith residue studies already undertaken (e.g., Fullagar et al. 2015). Likewise, lipid studies may determine whether the grindstones were used to extract oil from sesame seeds, potentially providing a direct link between the recovered macrobotanical remains and crop processing methods. In any case, the ongoing integration of these and other archaeological science techniques will no doubt forge new understandings of the timing, complexity, and regional variability of the transition to food production in what is clearly a key region of the world.

Ravi Korisettar
Department of Art and Archaeology, Karnatak University, Dharwad 580 003, India (korisettar@gmail.com). 25 IX 15

The paper by García-Granero et al. breaks new ground and endeavors to identify the Anarta region of modern Gujarat as one of several independent centers of the origins of agriculture in the Indian subcontinent. At the outset, I would like to agree with the authors and note that the authors have attempted an elucidation of the evidence from only a couple of sites in North Gujarat (Anarta). These two sites bear evidence for transformation of lifeways from hunting-gathering to agropastoral, from the so called Mesolithic to Chalcolithic. As revealed by the material culture sequence of two distinctive cultural phases have been identified, Mesolithic and Chaloclithic. One is not clear of the existence of the Neolithic substratum here at other settlements falling in this time range, before the emergence of Chalcolithic agricultural economies. Further, it is also not very clear whether Anarta possesses unique geographical environments in comparison with Saurashtra and the rest of Gujarat, though there may be topographic variations between them.

In recent archaeobotanical research, there is greater emphasis on recovering microbotanical remains as important proxy data for reconstructing plant domestication. Phytoliths and starch grains provide evidence related to the practice of irrigated agriculture, dry farming, and vegeculture, including crop processing activities. The advantages of microremains is twofold: (1) they increase the scope of identification of taxa, and (2) they facilitate recognition of taxa from leaves, roots, tubers, and fruits. In addition, stone tools such as grinding stones also provide direct evidence of dietary habits of the agricultural communities. García-Granero et al. have made a systematic effort to recover multiproxy data from two neighboring sites, Loteshwar and Vaharvo Timbo in North Gujarat. Recovered macroremains include seeds and charred grains; microremains include phytoliths and starch remains and grinding stones. Microremains, however, have proved difficult to identify. Armed with these sets of data, the authors have set out to (1) test a generalized hypothesis on the origins of agriculture in the semiarid regions (Fuller 2006), including Gujarat; (2) test the existence of a local millet-based agricultural economy before the establishment of Harappan urban settlements; and (3) recognize Anarta as an independent center of agricultural origins before the expansion of Harappan Civilization. The pre-urban Harappan settlements are identified with the Anarta Chalcolithic culture, which has a time bracket of 3681–2243 cal BC.

The vast Indian subcontinent is a network of distinctive ecosystems that are characterized by endemic plant and animal communities. These ecosystems are covered by the Indian monsoon circulation, both summer and winter monsoons. The latitudinal and longitudinal variation in the precipitation regimes across the subcontinent has given rise to mangrove, tropical evergreen, savanna, semiarid, and arid evergreen scrublands and desert ecosystems. Hunter-gatherer and early agropastoral settlements have been documented in profusion from these ecosystems, revealing the fact that fluctuating paleoclimate regimes favored human adaptations to these ecosystems during times of climate amelioration as well as deterioration. Strong seasonality of the Indian monsoon also governed the mobility range of these communities, who were exposed to distinctive plant food resources.

The semiarid monsoonal regions of the Indian subcontinent, such as Gujarat and the southern peninsula (excluding Kerala), were considered secondary centers of agricultural origins. Many scholars were of the view that local crops were domesticated after the introduction of crops of African origin and that the first agricultural settlers facilitated their inclusion into their food package. Over the past decade and a half, systematic archaeobotanical investigations into regional early agropastoral settlements have led to a paradigm shift emphasizing domestication of local crops before the spread of crops either from Southwest Asia or Africa. This paper by García-Granero et al. is a step forward in this direction.

Geophytology of a variety of wild plant food resources across the subcontinent has identified a suit of native plant food resources and other economic crops, including cereals, millets, pulses, oil, and fiber seeds. While some have widespread distribution, others are restricted to particular ecosystems. For examples, small millets are known to have a widespread distribution in monsoonal semiarid regions of peninsular south India and Gujarat and native pulses in the deciduous ecosystems of Western and Eastern Ghats. Archaeobotanical research at a number agropastoral settlements falling in the time range between the third and second millennia BC has revealed the importance of small millets in the early agricultural societies in these regions. In addition, this evidence has been firmly dated by the application of the accelerator mass spectrometry radiocarbon method, in some cases directly on the archaeological grains. Existence of independent early, small millet–based agropastoral economies has long been envisaged (Ajithprasad 2002; Ajithprasad and Sonawane 2011; Posselhl 1992). As many as seven such centers have been identified, including Gujarat (Fuller 2006).

There are nearly a dozen varieties of small millet species cultivated in India, and they have different geographical origins. For instance, some of the small millets that have their provenance in peninsular south India are browntop millet (*Brachiaria ramose*), sawa millet (*Echinochloa colona* ssp.), proso millet (*Panicum miliacum*), kodo millet (*Paspalum scrobiculatum* L.), little millet (*Panicum sumatrense* Roth), and bristley foxtail millet (*Sataria verticillata*). These and several other related small millets have received considered attention in the current archaeobotanical literature. In the context of identifying independent centers of agricultural origins within the Indian subcontinent, our knowledge of their provenance is critical to elucidating the process of domestication in the archaeological context. Criteria for identifying millet species in the archaeobotanical samples has been worked out for India, and the fact that sorghum and elusine millets are of African origin is well founded.

Although cultivation of native crops in Gujarat was hypothesized early on (Ajithprasad 2002; Sonawane 2000) before the introduction of African large millets and Southwest Asian cereal crops, direct archaeobotanical documentation in Gujarat was not undertaken. This is the first time García-Granero et al. have made a systematic documentation of archaeobotanical material in a dated context from North Gujarat (Anarta). While all the earlier archaeobotanical evidence came from Harappan sites and a non-Harappan site of Padri in the Saurashtra peninsula of Gujarat, this evidence from north Gurjarat is a major breakthrough. This research has pushed back the antiquity of agricultural origins to the fourth millennium BC, and the evidence from Anarta clearly points toward existence of ecologically suitable conditions for an early transition to agriculture focusing on local millets. In view of the ubiquitous presence of small millets in the Saurshtra region of Gujarat, the possibility of early domestication of monsoon-adapted local millets—particularly *Panicum sumatrenese* and *Setaria*—was hypothesized, pending documentation from non-Harappan archaeological contexts (Fuller 2006).

There are some prerequisites for making a case for an independent center of agricultural origins: first and foremost is systematic documentation of evidence for morphological domestication, which is lacking in Indian archaeobotanical research; second, for many taxa, reliable characters based on modern reference data are not well established; third, information on spikelet bases in terms of wild type or domestic type seed dispersal is essential. For the latter, some preliminary studies were carried out (Fuller 1999), but similar work appears to be absent in this study. Further, Fuller et al. (2004) have explained, on the basis of identification of nonbrittle spikelets from among archaeobotanical remains from Neolithic sites (12 sites) in peninsular south India, to place Southern Neolithic as an independent center of agricultural origins, on the basis of adoption of a suit of crops similar to what has been considered by García-Granero et al. It is expected that these authors made such an attempt.

The evidence presented here by García-Granero et al. clearly indicates the existence of sedentary agriculture during the time period from the mid third millennium BC and antedates the similar evidence from the Southern Neolithic of India (Fuller et al. 2009). The presence of wild *Sesamum* sp. Grains is significant and that it is was present in the region during mid- Holocene is important. What is required is elucidation of millet-pulse-livestock relationship in the given environmental context, especially the native crops. Absence of clear information on wild forms of the domesticated grains remains a major lacuna. Despite a good suit of radiocarbon dates, what is not clear is the precursors to the beginnings of sedentism, the beginnings of ceramic production (especially in the absence of distinctive Neolithic substratum), and the transition to foraging of wild millets to cultivation and morphological domesticates. This has been an essential requirement in Indian archaeobotanical research spanning the time period from fourth to third millennia BC. I wonder why this issue has not been addressed by the authors. Another important requirement is direct AMS dating of the archaeobotanical grains. Criteria for determining wild versus domestic grains would facilitate a solid ground for making a case for Anarta as an independent center of agricultural origins. Along with this, documentation of weed assemblages is crucial to reconstructing independent center of agricultural origins. Although the authors state that the study area has the potential for elucidating local domestication of *Bos indicus*, their data do not deal with a documentation of evidence for morphological change from wild to domesticated forms of cattle.

The proxy data generated by the authors deserved a comparative study of more robust data from southern Deccan Neolithic sites, where millet cultivation dominated the early agricultural practices. Although the authors mention the presence of spikelet bases (from Vaharvo Timbo) of four different species of wild grasses, which of them were later domesticated is not clear. This information would have been useful to archaeologists like myself.

Alison Weisskopf
Institute of Archaeology, University College London, Room 313B, 31–34 Gordon Square, London WC1H 0PY, United Kingdom (a.weisskopf@ucl.ac.uk). 3 IX 15

This article provides welcome new archaeobotanical information from a part of the world that has, in the past, lacked systematically recovered archaeobotanical data. A major aim of this study is the use of an integrated multiproxy approach to explore the comparatively neglected role of plants in the subsistence of pre-Harappan populations in the semiarid region of north Gujarat, India. The authors analyze archaeobotanical assemblages of charred seeds, phytoliths, and starches from two pre-Harappan sites: hunter-gatherer-occupied Vaharvo Timbo (5600–5000 BC) and Loteshwar, where both Mesolithic hunter-gatherer (7168–4703 cal BC) and Arnata (3681–2243 cal BC) contexts are examined as well as phytoliths and starches from grinding stones. In doing so, they aim to understand how people responded to changes in water availability caused by a weakening monsoon from ca. 7000 years ago and assess whether there is evidence that seminomadic pastoralists also cultivated plants, in particular small millets, *Brachiaria*, *Echinochloa*, and *Setaria*. They also seek evidence for indigenous primary domestications of some small millets, legumes, for example, *Macrotyloma* and sesame taking place in Gujarat during the mid Holocene, which the authors suggest may have been a response to the environmental stress of aridification.

So do they succeed? As they state, there is evidence worldwide for nomadic pastoralists utilizing wild grasses and integrating wild grass cultivation today as well as in the past (Hugot 1968 and references therein). While the macrobotanical evidence from Vaharvo Timbo is slight—only three identified seed taxa—they are all wild and accompanied by relatively high proportions of Poaceae spikelet bases from several genera supporting the argument for wild grass exploitation by the hunter gatherers. The presence of four Arecaceae phytoliths is probably not enough to suggest a systematic use of wild palm (*Phoenix sylvestris*), but it is interesting to note the implications of their presence, along with some phytoliths from sedges and the presence of Pooid grasses, which all point to utilization of the plants from more humid areas. Loteshwar has only one quantifiable sample from the Mesolithic level, again with very few macrobotanical remains, two of which are sedges, and few identifiable phytoliths. The authors rely heavily on the starches from the grinding stones to provide evidence for their interpretation of a broad-spectrum economy during the early to mid Holocene.

The argument for seminomadic pastoralism using interdunal cultivation of *kharif* crops in the Chalcolithic North Gujerat seems robust. The small millets and other plants found in the Arnata levels at Loteshwar—for example, sesame—have a short growing season and are suitable for exploiting highly seasonal niche cultivation. The authors provide a parallel with traditional mixed agriculture today in Kachchh. The phytolith evidence for threshing at Loteshwar is somewhat scanty; it would be interesting to know the proportion of silica skeletons with threshing marks. The paper cited (Cumings 2007) suggests that these marks can be caused only by threshing sledges. Is there evidence for threshing sledges being used in Gujerat at this time? Could these clean-cut edges be caused by anything else? For example, trampling by cattle, which is still used to process crops in India today, or other taphonomic processes? In my experience of looking at phytoliths from contexts containing crop processing waste from many Neolithic Lower Yangtze sites, silica skeletons often have quite clean breaks at the edges, but there is no artifactual evidence that threshing sledges were being used there.

While the authors argue the presence and cultivation of native taxa alongside other plants considered as weeds over thousands of years in the region supports the argument for local indigenous domestication, the data set they present here is small. The issue of the difficulty in actually seeing domestication of small millets is raised. The seeds do not change morphologically, and many species still grow wild and as crop weeds. The legumes present a similar problem, and the same can be said for sesame. There are also issues with dating and stratigraphy at Loteshwar. The theoretical argument is strong, but the actual physical evidence is slight. As the authors state, “Further evidence and a more robust chronology is needed.” The paper ably demonstrates the value of a multiproxy approach and highlights what is possible with a systematic and thorough archaeobotanical analysis.

Reply

We heartily thank the commentators for their remarks on our article. They offer valuable insights and contribute powerful ideas for further strengthening our model that we will most certainly implement in our future research.

As Alison Crowther and Ravi Korisettar point out, the chronology of the phenomenon under analysis—the adoption of domesticates in Northern Gujarat—is somewhat dubious, and direct dating of the archaeological seeds could greatly improve it. However, the existence of an extensive set of radiocarbon dates (particularly for Loteshwar) and the scarcity of macrobotanical remains in both sites, as remarked on also by Alison Weisskopf, induced us to initially discard this possibility. This said, we will certainly consider this approach once we assess the remaining material recovered during the excavation of both sites. Similarly, Korisettar remarks on the absence of a Neolithic phase, especially at the site of Loteshwar, where the two phases of occupation were identified as Mesolithic and Chalcolithic. Bearing in mind that these terms were introduced to define a periodization based on lithic industry, they have become common terms used to define both a subsistence economy and a chronology. Most of the times, it is not completely clear whether, by the terms Mesolithic or Neolithic, we refer to the chronology or to the way of life. In addition, recent research seems to suggest that the correlation between these terms and the subsistence strategies applied by the people is not straightforward and as dogmatic as it used to be considered (Smith 2001). Thus, if it is true that Loteshwar does not seem to have a Neolithic substratum (where Neolithic is used to indicate a chronological period), it is undeniable that it presents all the characteristics of a Neolithic way of life in terms of subsistence practices—incipient agriculture, presence of mixed wild and domestic crops and animals.

The other major issue rose by Korisettar and Weisskopf is the fact that the model presented in this paper is based on scanty evidence, both in regards to number of sites (“only” two) and botanical evidence. We should keep in mind that, to date, only three sites in North Gujarat (five if we include the adjoining Peninsula of Saurashtra) have been radiocarbon dated to the mid-Holocene. Focusing on North Gujarat, the other mid-Holocene occupation is documented in Datrana IV, a lithic blade workshop located ca. 75 km west of Loteshwar and Vaharvo Timbo (Ajithprasad 2002, 2011; Gadekar, Ajithprasad, and Madella 2013; Rajesh et al. 2013; Sonawane and Ajithprasad 1994). A recent analysis of the archaeobotanical evidence recovered from Datrana IV by the members of the NoGAP project in 2010 yielded very few remains, both macro and microbotanical (García-Granero et al. 2015), thus precluding the use of these data in the debate at hand. On the other hand, a thorough archaeobotanical analysis of the mid-Holocene contexts documented in the Saurashtran coast (Padri in the east and Prabhas in the south) is still lacking. Hence, our model, which actually considers all the presently available evidence, will certainly be refined to incorporate new data resulting from future research in this region.

Further comments include the possible application of use-wear and lipid analyses, the use of grass spikelets to identify small millet domestication, and the use of the threshing sledge in Anarta North Gujarat. First, Crowther remarks on the suitability of carrying out further analyses on the grinding stones considered in this study. Applying such techniques as use-wear and lipid analyses would certainly help further understanding the use of the grinding tools; we believe, however, that they might not necessarily contribute to the debate at hand, that is, whether North Gujarat can be considered an independent center for the origin of plant cultivation. Second, Korisettar mentions the potential of small millet spikelets to determine whether a domestication process was already taking place, despite the lack of morphological changes in the grains themselves. This approach, successfully applied by Dorian Fuller in southern India (Fuller et al. 2004), could not be considered in this study because of the scarcity of chaff remains recovered at Loteshwar. Similarly, the few wild grass spikelets recovered at Vaharvo Timbo could not be further identified taxonomically, and thus it is not possible to determine whether the grasses exploited by hunter-gatherers were later cultivated by Anarta populations. Hopefully, further research in this area will provide more archaeobotanical evidence that will help clarify the plant domestication process. Finally, Weisskopf inquires about the nature of the potential threshing marks identified on silica skeletons from Loteshwar and the use of the threshing sledge by the Anarta populations. Long, diagonal, straight cuts occurring in silica skeletons have been associated with the use of threshing sledges as opposed to the convex, jagged, irregular cuts that are produced by trampling or pounding (Anderson 2003). The fragmentation observed in the silica skeletons was mostly of the first type and therefore definitely caused by some kind of threshing. However, we agree with Weisskopf's suggestion that they were not necessarily caused by a threshing sledge, although this possibility cannot be discarded. Further ethnographic and experimental research on the cuts produced by cattle trampling and other processing methods should be considered to determine which was the *chaîne opératoire* used at Loteshwar. However, we considered that the existence of such marks was worth mentioning because they suggest that some stages of the plant processing were taking place on site and thus offered valuable insights into the daily life of the mid-Holocene inhabitants of Loteshwar. To conclude, we concur with Crowther's statement that " the ongoing integration of these and other archaeological science techniques will no doubt forge new understandings of the timing, complexity, and regional variability of the transition to food production in what is clearly a key region of the world." In this regard, we hope that ongoing research within the NoGAP project will shed new light on the complex process that is the transition from food gathering to food production in North Gujarat.

—Juan José García-Granero, Carla Lancelotti,
Marco Madella, and P. Ajithprasad

References Cited

Ajithprasad, P. 2002. The pre-Harappan cultures of Gujarat. In *Indian archaeology in retrospect*, vol. 2 of *Protohistory: archaeology of the Harappan Civilization*. S. Settar and Ravi Korisettar, eds. Pp. 129–158. New Delhi: Manohar.

———. 2004. Holocene adaptation of the Mesolithic and Chalcolithic settlements in North Gujarat. In *Monsoon and civilizations*. Y. Yasuda and Vasant Shinde, eds. Pp. 115–132. New Delhi: Roli.

———. 2011. Chalcolithic cultural patterns and the Early Harappan interaction in Gujarat. In *Cultural relations between the Indus and the Iranian Plateau during the third millennium BCE*. Toshiki Osada and Michael Witzel, eds. Pp. 11–40. Harvard Oriental Series, Opera Minora vol. 7. Cambridge, MA: Harvard University.

Ajithprasad, P., and V. H. Sonawane. 2011. The Harappan culture in North Gujarat: a regional paradigm. In *Linguistics, archaeology and human past*. Tashiki Osada and Hitoshi Endo, eds. Pp. 223–269. Occasional Paper 12. Kyoto: Research Institute for Humanity and Nature.

Albert, Rosa Maria, and Steve Weiner. 2001. Study of phytoliths in prehistoric ash layers from Kebara and Tabun Caves using a quantitative approach. In *Phytoliths: applications in earth sciences and human history*. Jean Dominique Meunier and Fabrice Colin, eds. Pp. 251–266. London: Taylor & Francis.

An, Cheng-Bang, Lingyu Tang, Loukas Barton, and Fa-Hu Chen. 2005. Climate change and cultural response around 4000 cal yr B.P. in the western part of Chinese Loess Plateau. *Quaternary Research* 63:347–352.

Anderson, Patricia C. 2003. Observations on the threshing sledge and its products in ancient and present-day Mesopotamia. In *Le traitement des récoltes: un regard sur la diversité du Néolithique au présent*. Patricia C. Anderson, Linda S. Cummings, Thomas K. Schippers, and B. Simonel, eds. Pp. 417–438. Paris: Centre National de la Recherche Scientifique.

Balbo, Andrea L., Dan Cabanes, Juan José García-Granero, Anna Bonet, P. Ajithprasad, and Xavier Terradas. 2015. A microarchaeological approach for the study of pits. *Environmental Archaeology* 20:390–405.

Balbo, Andrea L., Bernardo Rondelli, Francesc Cecília Conesa, Carla Lancelotti, Marco Madella, and P. Ajithprasad. 2013. Contributions of geoarchaeology and remote sensing to the study of Holocene hunter-gatherer and agro-pastoral groups in arid margins: the case of North Gujarat (Northwest India). *Quaternary International* 308/309:53–65.

Balbo, Andrea L., X. Rubio-Campillo, B. Rondelli, M. Ramírez, C. Lancelotti, A. Torrano, M. Salpeteur, et al. 2014. Agent-based simulation of Holocene monsoon precipitation patterns and hunter-gatherer population dynamics in semi-arid environments. *Journal of Archaeological Method and Theory* 21:426–446.

Barh, Debmalya, and B. C. Mazumdar. 2008. Comparative nutritive values of palm saps before and after their partial fermentation and effective use of wild date (*Phoenix sylvestris* Roxb.) sap in treatment of anemia. *Research Journal of Medicine and Medical Sciences* 3(2):173–176.

Barton, H., and P. Matthews. 2006. Taphonomy. In *Ancient starch research*. R. Torrence and H. Barton, eds. Pp. 75–94. Walnut Creek, CA: Left Coast. [AC]

Bedigian, Dorothea. 2003. Evolution of sesame revisited: domestication, diversity and prospects. *Genetic Resources and Crop Evolution* 50:779–787.

———. 2004. History and lore of sesame in southwest Asia. *Economic Botany* 58:329–353.

Bhan, Kuldeep K. 1994. Cultural development of the prehistoric period in North Gujarat with reference to western India. *South Asian Studies* 10:71–90.

Bouby, Laurent, Gilbert Fages, and Jean Michel Treffort. 2005. Food storage in two Late Bronze Age caves of southern France: palaeoethnobotanical and social implications. *Vegetation History and Archaeobotany* 14:313–328.

Brooks, Nick, Natasha Grist, and Katrina Brown. 2009. Development futures in the context of climate change: challenging the present and learning from the past. *Development Policy Review* 27(6):741–765.

Cappers, René T. J., and Renée M. Bekker. 2013. *A manual for the identification of plant seeds and fruits*. Groningen Archaeological Studies vol. 23. Eelde: Barkhuis.

Cappers, René T. J., Reinder Neef, and Renée M. Bekker. 2009. *Digital atlas of economic plants*. Groningen Archaeological Studies vol. 9. Eelde: Barkhuis.

Chang, Claudia, Norbert Benecke, Fedor P. Grigoriev, Arlene M. Rosen, and Perry A. Tourtellotte. 2003. Iron Age society and chronology in South-east Kazakhstan. *Antiquity* 77(296):298–312.

Chase, Brad, P. Ajithprasad, S. V. Rajesh, Ambika Patel, and Bhanu Sharma. 2014. Materializing Harappan identities: unity and diversity in the borderlands of the Indus Civilization. *Journal of Anthropological Archaeology* 35:63–78.

Conesa, Francesc C., Núria Devanthéry, Andrea L. Balbo, Marco Madella, and Oriol Monserrat. 2014. Use of satellite SAR for understanding long-term human occupation dynamics in the monsoonal semi-arid plains of North Gujarat, India. *Remote Sensing* 6:11420–11443.

Conesa, Francesc C., Marco Madella, Nikolaos Galiatsatos, Andrea L. Balbo, S. V. Rajesh, and P. Ajithprasad. 2015. CORONA photographs in monsoonal semi-arid environments: addressing archaeological surveys and historic landscape dynamics over North Gujarat, India. *Archaeological Prospection* 22:75–90.

Costanza, Robert, Lisa Graumlich, Will Steffen, Carole Crumley, John Dearing, Kathy Hibbard, Rik Leemans, Charles Redman, and David Schimel. 2007. Sustainability or collapse: what can we learn from integrating the history of humans and the rest of nature? *Ambio* 36(7):522–527.

Crowther, Alison, Michael Haslam, Nikki Oakden, Dale Walde, and Julio Mercader. 2014. Documenting contamination in ancient starch laboratories. *Journal of Archaeological Science* 49:90–104.

Cummings, Linda S. 2007. Phytoliths as artifacts: evidence of threshing on silica bodies. In *Plants, People and Places*. Marco Madella and Débora Zurro, eds. Pp. 151–154. Oxford: Oxbow.

Davis, T. A., and Dennis V. Johnson. 1987. Current utilization and further development of the palmyra palm (*Borassus flabellifer* L., Arecaceae) in Tamil Nadu state, India. *Economic Botany* 41(2):247–266.

de Zoysa, Neela. 1992. Tapping patterns of the Kitul palm (*Caryota urens*) in the Sinharaja Area, Sri Lanka. *Principes* 36:28–33.

Di Cosmo, Nicola. 1994. Ancient Inner Asian nomads: their economic basis and its significance in Chinese history. *Journal of Asian Studies* 53(4):1092–1126.

Dillehay, Tom D., and Alan L. Kolata. 2004. Long-term human response to uncertain environmental conditions in the Andes. *Proceedings of the National Academy of Sciences of the USA* 101(12):4325–4330.

Fogg, Wayne H. 1983. Swidden cultivation of foxtail millet by Taiwan aborigines: a cultural analogue of the domestication of *Setaria italica* in China. In *The origins of Chinese Civilization*. David N. Keightley, ed. Berkeley: University of California.

Ford, R. I. 1985. The processes of plant food production in prehistoric North America. In *Prehistoric food production in North America*. R. I. Ford, ed. Pp. 1–18. Anthropological Papers 75. Ann Arbor: University of Michigan, Museum of Anthropology.

Fullagar, R. L. K., E. Hayes, B. Stephenson, J. Field, C. Matheson, N. Stern, and K. Fitzsimmons. 2015. Evidence for Pleistocene seed grinding at Lake Mungo, South-Eastern Australia. *Archaeology in Oceania* 50:3–19. [AC]

Fuller, Dorian Q. 1999. The emergence of agricultural societies in south India: botanical and archaeological perspectives. PhD dissertation, University of Cambridge.

———. 2003. Further evidence on the prehistory of sesame. *Asian Agri-History* 7:127–137.

———. 2006. Agricultural origins and frontiers in South Asia: a working synthesis. *Journal of World Prehistory* 20:1–86.

———. 2011. Finding plant domestication in the Indian subcontinent. *Current Anthropology* 52(suppl.):S347–S362.

Fuller, Dorian Q, and Robin Allaby. 2009. Seed dispersal and crop domestication: shattering, germination and seasonality in evolution under cultivation. *Annual Plant Reviews* 38:238–295.

Fuller, Dorian Q, N. Boivin, C. Castillo, T. Hoogervorst, and R. G. Allaby. 2014. The archaeobiology of Indian Ocean translocations: current outlines of cultural exchanges by proto-historic seafarers. In *Maritime contacts of the past deciphering connections amongst communities*. Tripati, ed. Pp. 1–23. New Delhi: Delta Book World. [AC]

Fuller, Dorian Q, and Emma L. Harvey. 2006. The archaeobotany of Indian pulses: identification, processing and evidence for cultivation. *Environmental Archaeology* 11:219–246.

Fuller, Dorian Q, Ravi Korisettar, P. C. Venkatasubbaiah, and Martin K. Jones. 2004. Early plant domestications in southern India: some preliminary archaeobotanical results. *Vegetation History and Archaeobotany* 13:115–129.

Fuller, Dorian Q, and Marco Madella. 2002. Issues in Harappan archaeobotany: retrospect and prospect. In *Indian archaeology in retrospect*, vol. 2 of *Protohistory: archaeology of the Harappan Civilization*. S. Settar and Ravi Korisettar, eds. Pp. 317–390. New Delhi: Manohar.

Fuller, Dorian Q, and Charlene Murphy. 2014. Overlooked but not forgotten: India as a center for agricultural domestication. *General Anthropology* 21:1–8.

Gadekar, Charusmita, P. Ajithprasad, and Marco Madella. 2013. Crested ridge technique and lithic assemblage from Datrana, Gujarat. *Heritage: Journal of Multidisciplinary Studies in Archaeology* 1:16–28.

Gadekar, Charusmita, P. Ajithprasad, M. Madella, A. Balbo, S. V. Rajesh, B. Rondelli, J. J. García-Granero, D. Rodríguez, and V. Yanitto. 2014. Continuation of a tradition over five thousand years: lithic assemblage from Loteshwar, North Gujarat, western India. *Heritage: Journal of Multidisciplinary Studies in Archaeology* 2.

García-Granero, Juan José. 2011. Combined phytolith and starch grain analyses from grinding stones from Loteshwar (North Gujarat, India). MSc thesis, University College London.

García-Granero, Juan José, Charusmita Gadekar, Irene Esteban, Carla Lancelotti, Marco Madella, and P. Ajithprasad. 2015. What is on the craftsmen's menu? plant consumption at Datrana, a 5000-year-old lithic blade workshop in North Gujarat, India. *Archaeological and Anthropological Sciences*. doi:10.1007/s12520-015-0281-0.

García-Granero, Juan José, Carla Lancelotti, and Marco Madella. 2015. A tale of multi-proxies: integrating macro and microbotanical remains to understand subsistence strategies. *Vegetation History and Archaeobotany* 24:121–133.

———. 2016. A methodological approach to the study of microbotanical remains from grinding stones: a case study in northern Gujarat (India). *Vegetation History and Archaeobotany*. doi:10.1007/s00334-016-0557-z.

García-Granero, Juan José, Carla Lancelotti, Marco Madella, and P. Ajithprasad. Forthcoming. Plant processing activities at Loteshwar (North Gujarat, India): a micro-botanical approach. In *Man and environment in prehistoric and protohistoric South Asia: new perspectives*. Vincent Lefèvre, Aurore Didier, and B. Mutin, eds. Pp. 99–116. Turnhout: Brepols.

Gasse, F., J.Ch. Fontes, E. van Campo, and K. Wei. 1996. Holocene environmental changes in Bangong Co basin (Western Tibet). Part 4. Discussion and conclusions. *Palaeogeography, Palaeoclimatology, Palaeoecology* 120:79–92.

Gupta, Anil K., David M. Anderson, Deep N. Pandey, and Ashok K. Singhvi. 2006. Adaptation and human migration, and evidence of agriculture coincident with changes in the Indian summer monsoon during the Holocene. *Current Science* 90:1082–1090.

Harris, David R. 1996. Domesticatory relations of people, plants and animals. In *Redefining nature: ecology, culture, and domestication*. R. F. Ellen and Katsuyoshi Fukui, eds. Pp. 437–463. Oxford: Berg.

Haslam, M. 2004. The decomposition of starch grains in soils: implications for archaeological residue analyses. *Journal of Archaeological Science* 31 (12):1715–1734. [AC]

Henry, Amanda G., Holly F. Hudson, and Dolores R. Piperno. 2009. Changes in starch morphologies from cooking. *Journal of Archaeological Science* 36:915–922.

Hu, C., G. M. Henderson, J. Huang, S. Xie, Y. Sun, and K. R. Johnson. 2008. Quantification of Holocene Asian monsoon rainfall from spatially separated cave records. *Earth and Planetary Science Letters* 266:221–232.

Hugot, H. J. 1968. The origins of agriculture: Sahara. *Current Anthropology* 9 (5):483–488. [AW]

International Code for Starch Nomenclature (ICSN). 2011. *The International Code for Starch Nomenclature*. http://www.fossilfarm.org/ICSN/Code.html (accessed October 29, 2014).

Jones, Glynis. 1992. Weed phytosociology and crop husbandry: identifying a contrast between ancient and modern practice. *Review of Palaeobotany and Palynology* 73:133–143.

Khare, C. P., ed. 2007. *Indian medicinal plants: an illustrated dictionary*. Berlin: Springer.

Khazanov, Anatoly M. 1984. *Nomads and the outside world*. Madison: University of Wisconsin.

Kimata, M., E. G. Ashok, and A. Seetharam. 2000. Domestication, cultivation and utilization of two small millets, *Brachiaria ramosa* and *Setaria glauca* (Poaceae), in South India. *Economic Botany* 54:217–227.

Kuper, Rudolph, and Stefan Kröpelin. 2006. Climate-controlled Holocene occupation in the Sahara: motor of Africa's evolution. *Science* 313:803–807.

Larson, G., D. R. Piperno, R. G. Allaby, M. D. Purugganan, L. Andersson, M. Arroyo-Kalin, L. Barton, et al. 2014. Current perspectives and the future of domestication studies. *Proceedings of the National Academy of Sciences of the United States of America* 111(17):6139–6146. [AC]

Lightfoot, E., G. Motuzaite-Matuzeviciute, T. C. O'Connell, I. A. Kukushkin, V. Loman, V. Varfolomeev, X. Liu, and M. K. Jones. 2014. How "pastoral" is pastoralism? dietary diversity in Bronze Age communities in the Central Kazakhstan steppes. *Archaeometry*. doi:10.1111/arcm.12123.

Liu, Z., B. Otto-Bliesner, J. Kutzbach, L. Li, and C. Shields. 2003. Coupled climate simulation of the evolution of global monsoons in the Holocene. *Journal of Climate* 16:2472–2490.

Madella, Marco, P. Ajithprasad, Andrea Balbo, Jorge Caro Saiz, Francesc Cecilia, Juan José García-Granero, Carla Lancelotti, et al. 2012. The North Gujarat Archaeological Project (NoGAP)'s 2011 field season: interdisciplinary methods for the study of Holocene socio-ecological contexts. In *Informes y Trabajos. Excavaciones en el exterior 2011*. Secretaría General Técnica, ed. Pp. 261–272. Madrid: Ministerio de Educación, Cultura y Deporte. [In Spanish.]

Madella, Marco, P. Ajithprasad, C. Lancelotti, B. Rondelli, A. Balbo, D. Rodríguez, et al. 2010. Social and environmental transitions in arid zones: the North Gujarat Archaeological Project—NoGAP. *Antiquity* 84(325).

Madella, Marco, A. Alexandre, and T. Ball. 2005. International code for phytolith nomenclature 1.0. *Annals of Botany* 96:253–260.

Madella, Marco, A. Balbo, B. Rondelli, D. Rodríguez, V. Yannitto, P. Ajithprasad, C. Gadekar, et al. 2011. North Gujarat Archaeological Project. In *Informes y Trabajos 5. Excavaciones en el exterior 2009*. Secretaría General Técnica, ed. Pp. 114–119. Madrid: Ministerio de Cultura. [In Spanish.]

Madella, Marco, and Carla Lancelotti. 2012. Taphonomy and phytoliths: a user manual. *Quaternary International* 275:76–83.

Madella, Marco, Carla Lancelotti, and Juan José García-Granero. 2013. Millet microremains—an alternative approach to understand cultivation and use of critical crops in Prehistory. *Archaeological and Anthropological Sciences*. doi:10.1007/s12520-013-0130-y.

Mahapatra, S. K., ed. 1995. *Indian archaeology 1991–92—a review*. New Delhi: Archaeological Survey of India.

Manidool, C. 1992. *Dactyloctenium aegyptium* (L.) Willd. In *Plant resources of South-East Asia no. 4: forages*. L. Mannetje and R. M. Jones, eds. Pp. 104–105. Wageningen: Pudoc.

Marshall, Fiona, and Elisabeth Hildebrand. 2002. Cattle before crops: the beginnings of food production in Africa. *Journal of World Prehistory* 16:99–143.

Motuzaite-Matuzeviciute, G., R. A. Staff, H. V. Hunt, X. Liu, and M. K. Jones. 2013. The early chronology of broomcorn millet (*Panicum miliaceum*) in Europe. *Antiquity* 87:1073–1085. [AC]

Murphy, C., and D. Q Fuller. 2014. Plant domestication in India. In *Encyclopaedia of the history of science, technology, and medicine in Non-Western cultures*. Helaine Selin, ed. Dordrecht: Springer. doi:10.1007/978-94-007-3934-5_10005-1. [AC]

Murphy, Eileen M., Rick Schulting, Nick Beer, Yuri Chistov, Alexey Kasparoc, and Margarita Pshenitsyna. 2013. *Journal of Archaeological Science* 40:2547–2560.

Neef, Reinder, René T. J. Cappers, and Renée M. Bekker. 2012. *Digital atlas of economic plants in archaeology*. Groningen Archaeological Studies vol. 17. Eelde: Barkhuis.

Overpeck, Jonathan, David Anderson, Susan Trumbore, and Warren Prell. 1996. The southwest Indian Monsoon over the last 18,000 years. *Climate Dynamics* 12(3):213–225.

Pandey, Anjula, Ajay Kumar Tomer, D. C. Bhandari, and S. K. Pareek. 2007. Towards collection of wild relatives of crop plants in India. *Genetic Resources and Crop Evolution* 55(2):187–202.

Parmar, S. P., K. A. Prajapati, Y. T. Jasrai, and S. K. Patel. 2012. Grasses and its diversity in Gujarat State: a review. *Life Sciences Leaflets* 10:56–66.

Parthasarathy, B., N. A. Sontakke, A. A. Monot, and D. R. Kothawale. 1987. Droughts/floods in the summer monsoon season over different meteorological subdivisions of India for the period 1871–1984. *Journal of Climatology* 7(1):57–70.

Patel, Ajita K. 2009. Occupational histories, settlements, and subsistence in western India: what bones and genes can tell us about the origins and spread of pastoralism. *Anthropozoologica* 44:173–188.

Piperno, Dolores R. 2006. *Phytoliths: a comprehensive guide for archaeologists and paleoecologists*. Lanham, MD: Altamira.

Pokharia, Anil K., Jeewan Singh Kharakwal, R. S. Rawat, Toshiki Osada, C. M. Nautiyal, and Alka Srivastava. 2011. Archaeobotany and archaeology at Kanmer, a Harappan site in Kachchh, Gujarat: evidence for adaptation in response to climatic variability. *Current Science* 100:1833–1846.

Possehl, Gregory L. 1992. The Harappan Civilization in Gujarat: Sorath and Sindhi Harappans. *Eastern Anthropologist* 45:117–154.

Prasad, Vandana, Binita Phartiyal, and Anupam Sharma. 2007. Evidence of enhanced winter precipitation and the prevalence of a cool and dry climate during the mid to late Holocene in mainland Gujarat, India. *Holocene* 17:889–896.

Purugganan, Michael D., and Dorian Q Fuller. 2009. The nature of selection during plant domestication. *Nature* 457:843–848.

Radomski, Kai Uwe, and Katharina Neumann. 2011. Grasses and grinding stones: inflorescence phytoliths from modern West African Poaceae and archaeological stone artefacts. In *Windows on the African past: current approaches to African archaeobotany*. Ahmed G. Fahmy, Stefanie Kahlheber, and A. Catherine D'Andrea, eds. Pp. 153–166. Frankfurt: Africa Magna.

Rajesh, S. V., K. Krishnan, P. Ajithprasad, and Marco Madella. 2013. Pre-Prabhas assemblage from Gujarat, western India. *Heritage: Journal of Multidisciplinary Studies in Archaeology* 1:181–209.

Reddy, Seetha Narahari. 1997. If the threshing floor could talk: integration of agriculture and pastoralism during the Late Harappan in Gujarat, India. *Journal of Anthropological Archaeology* 16:162–187.

Rosen, Arlene M., and Isabel Rivera-Collazo. 2012. Climate change, adaptive cycles, and the persistence of foraging economies during the late Pleistocene/Holocene transition in the Levant. *Proceedings of the National Academy of Sciences of the USA* 109(10):3640–3645.

Sankalia, H. D. 1987. *Prehistoric and historic archaeology of Gujarat*. New Delhi: Munshiram Manoharlal.

Singh, Anurudh K. 2010. Probable agricultural biodiversity heritage sites in India. VII. The arid western region. *Asian Agri-History* 14:337–359.

Singh, Vartika, Vandana Prasad, and Supriyo Chakraborty. 2007. Phytoliths as indicators of monsoonal variability during mid-late Holocene in mainland Gujarat, western India. *Current Science* 92:1754–1759.

Smith, Bruce D. 2001. Low-level food production. *Journal of Archaeological Research* 9:1–43.

Sonawane, V. H. 2000. Early farming communities of Gujarat, India. *Indo-Pacific Prehistory Association Bulletin* 19:137–146.

Sonawane, V. H., and P. Ajithprasad. 1994. Harappa culture and Gujarat. *Man and Environment* 19:129–139.

Spielmann, Katherine A., Margaret Nelson, Scott Ingram, and Matthew A. Peeples. 2011. Sustainable small-scalle agriculture in semi-arid environments. *Ecology and Society* 16(1):26.

Svyatko, Svetlana V., Rick J. Schulting, James Mallory, Eileen M. Murphy, Paula J. Reimer, Valeriy I. Khartanovich, Yury K. Chistov, and Mikhail V. Sablin. 2013. Stable isotope dietary analysis of prehistoric populations from the Minusinsk Basin, Southern Siberia, Russia: a new chronological framework for the introduction of millet to the eastern Eurasian steppe. *Journal of Archaeological Science* 40:3936–3945.

Tengberg, Margareta. 1999. Crop husbandry at Miri Qalat, Makran, SW Pakistan (4000–2000 B.C.). *Vegetation History and Archaeobotany* 8:3–12.

Thébaud, Brigitte, and Simon Batterbury. 2001. Sahel pastoralists: opportunism, struggle, conflict and negotiation. A case study from eastern Niger. *Global Environmental Change* 11(1):69–78.

Weber, Steven. 1999. Seeds of urbanism: palaeoethnobotany and the Indus Civilization. *Antiquity* 73:813–826.

Weber, Steven A., and Dorian Q Fuller. 2008. Millets and their role in early agriculture. *Pragdhara* 18:69–90.

Wei, K., and F. Gasse. 1999. Oxygen isotopes in lacustrine carbonates of West China revisited: implications for post glacial changes in summer monsoon circulation. *Quaternary Science Reviews* 18:1315–1334.

Wright, Katherine. 1992. A classification system for ground stone tools from the Prehistoric Levant. *Paléorient* 18(2):53–81.

Yang, Xioyan, and Linda Perry. 2013. Identification of ancient starch grains from the tribe Triticeae in the North China Plain. *Journal of Archaeological Science* 40:3170–3177.