Feeding ancient cities in South Asia: dating the adoption of rice, millet and tropical pulses in the Indus civilisation

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The first direct absolute dates for the exploitation of several summer crops by Indus populations are presented. These include rice, millets and three tropical pulse species at two settlements in the hinterland of the urban site of Rakhigarhi. The dates confirm the role of native summer domesticates in the rise of Indus cities. They demonstrate that, from their earliest phases, a range of crops and variable strategies, including multi-cropping were used to feed different urban centres. This has important implications for our understanding of the development of the earliest cities in South Asia, particularly the organisation of labour and provisioning throughout the year.

Keywords: South Asia, Indus civilisation, rice, millet, pulses

SI.1. Chronology of the Indus civilisation

The urban phase (*c*. 2600–1900BC) of the Indus civilisation was characterised by urban centres surrounded by fortification walls or built on platforms; houses, drains and wells made of mud-and/or fired-brick; a distinctive material culture assemblage marked by complex craft products; an un-translated script; and evidence for long-range interaction with other complex societies in Western and Central Asia (Marshall 1931; Piggott 1950; Sankalia 1962; Wheeler 1963; Allchin & Allchin 1968, 1982, 1997; Fairservis 1971; Chakrabarti 1995, 1999, 2006; Lal 1997; Kenoyer 1998; Possehl 2002; Agrawal 2007; Wright 2010; Petrie 2013). There is no universally acknowledged chronology or terminology used for the Indus civilisation. The most widely utilised chronological scheme is presented in Table S1 below.

Table S1. Chronology of the Indus civilisation.

Phase		Dates
Early village	early farming	6300–3200 BC
Early Harappan	pre-urban	3200–2600 BC
Mature Harappan	urban	2600–1900 BC
Late Harappan	post-urban	1900–1300 BC

SI.2. Variation in crop usage across the Indus zone

It is typically assumed that Indus cities were provisioned by crops grown in their immediate hinterlands (e.g. Wright 2010: 127). The nature of the relationship between Indus urban centres and the settlements in their hinterland regions has not yet been the focus of significant research, however, and issues of provisioning have typically been discussed on the basis of evidence from the urban centre alone (cf Petrie in press).

Mohenjo Daro

Only limited archaeobotanical work has been carried out at the Indus urban centre of Mohenjo-Daro, and what has been done, was conducted on hand-sorted samples collected during Sir John Marshall’s excavations in the 1920s (Marshall 1931). The grain seeds recovered included free-threshing wheat and barley (Mackay 1931; Luthra 1936). No summer crops have yet been reported from the site.

Harappa

The urban city-site of Harappa in central Punjab (Pakistan) is arguably the most important Indus settlement in archaeobotanical terms as it has a protracted sequence of occupation and systematic sampling for archaeobotanical analysis has been carried out over many seasons (Weber 1999, 2003). The archaeobotanical assemblage from Harappa shows that from the pre-urban Early Harappan period onwards the agricultural strategies at this Indus urban centre were dominated by the winter cereals wheat and barley, combined with the exploitation of some summer crops such as millet (*Panicum* sp.) (Weber 2003). This material has been used to support the suggestion that over time there was an increase in diversity, and a broadening of the agricultural strategy at Harappa through the evolution of a “complex multi-cropping strategy” (Weber 2003: 181), which conforms to Vishnu Mittre and Savithri’s (1982; also Chakrabarti

1988: 95) proposal that Indus populations practiced some form of multi-cropping involving both winter and summer crops. It is important to acknowledge, however, that the published evidence for cropping in two seasons at Harappa suggests that summer crops were a significant, but relatively minor component of the assemblage. Comprehension of the importance of summer crops is complicated by the fact that statistics on the frequency and proportions of individual crops are not yet available, though there has been some discussion of quantities in several publications. For instance it has been noted that “tens of thousands of small millet seeds” (Weber & Fuller 2008/09: 79), or that “over 10 000 Little millet seeds have been recovered from Harappa” (Weber & Kashyap 2013: 4). The total number of seeds from the site has been variously estimated at “nearly 150,000” (Weber & Fuller 2008/09: 79) or “hundreds of thousands”, so even at the most optimistic estimate, millet may have only comprised *c*.13.33% of the entire assemblage. The proportionally minor role of millet is also emphasised by the statistics on crops that have been published. Summer cereals, specifically millets, initially had a ubiquity of 9% in the Early Harappan period, and increased to appear in 19% of Mature Harappan and 47% of Late Harappan samples (Weber 2003: tab. 5.3a). However, these summer cereals only equate to 2% of the overall charred crop assemblage in the Early Harappan, a 4% in the Mature Harappan and a 7% in the Late Harappan periods (Weber 2003: Table 5.3c). Although it is clear that both summer and winter crops were being exploited at Harappa, it could be argued that the relatively low proportions of summer crops do not actually indicate extensive multi-cropping. This reconstruction is supported by Miller’s (2006) observation that the winter crops were clearly the most important staple at Harappa throughout the urban phase, and that it is only after the urban phase that the use of summer crops, and hence multi-cropping, becomes a major contributor to the crop assemblage.

Rojdi

Excavations at the small Indus settlement site of Rojdi in Gujarat during the 1980s gave clear indications that there was considerably more to Indus cereal exploitation than wheat and barley, with the discovery of a sequence of occupation deposits almost completely dominated by the exploitation of millets and other summer crops (Weber 1991, 1999). The composition of the assemblage remained fairly constant over the sequence: in Phase A (*c*.2500-2200BC) summer crops form *c*.98% of the crop assemblage with *Eleusine* sp. millet as the most dominant crop, alongside some *Panicum miliare*; in Phase B (*c*.2200-2000BC) summer crops are again the most dominant, comprising 99% of crops, with *Panicum miliare* being the most dominant; and in Phase C (*c*.2000-1700BC), *Setaria* cf. *glauca* and *Setaria* cf. *italica* were the component of the summer crop assemblage, which formed 91% of the overall assemblage (data converted from density tables in Weber 1989: 270, tab. 18; 299, tab. 23, 315, tab. 29). A slight decline in the role of summer crops was seen in the final mixed Late Harappan/Early Historic material of Phase C/D, with a reduction to 87% of the overall assemblage, and a mix of all three millet genera being attested (converted from density table in Weber 1989: 366–67, tab. 33). The crop assemblage at Rojdi is clearly different to that at Harappa.

Babar Kot

Such stability in the summer cropping regime has also been documented at other Gujarati Harappan settlement sites such as Babar Kot (Reddy 1994, 2003), where summer crops formed between 94 and 99.8% of the crop assemblage throughout the settlement's occupation with the main crops being millets, including *Panicum miliare* and *Setaria italica*, with the dominant species being dependent on period of occupation and context (Reddy 2003: 122, 129–30).

The differences noted between Gujarat and the Indus 'core' regions, as defined by the crop assemblage documented at Harappa, has previously been used to suggest that the Gujarati 'phenomenon' is unusual and a 'core/periphery' and 'intensive/extensive' model has developed as a result (Fuller & Madella 2002). The crop assemblage at Babar Kot is similar to that at Rojdi, but both are clearly different to that at Harappa.

Farmana

While presence/absence information is available from a number of Indus period archaeological sites in northwest India (e.g. Banawali, Balu and Kunal); the only site where any statistical information about the assemblage has been published is Farmana (Weber *et al*. 2011; Weber & Kashyap 2013). Although a range of winter and summer crops are attested, the main publication only presents presence and absence information for macro- and micro-botanical remains, and summative figures for seed density and ubiquity (Weber *et al*. 2011: tabs 11.1–11.2). Over time, there was a decline in the ubiquity of winter crops from 61 to 20%, and a decline of summer crops from 38 to 30%, and the authors interpreted as a shift in seasonal emphasis from a winter based strategy to one "more equally dependent upon both seasons" (Weber *et al*. 2011: 815). The one specific piece of information about proportions currently available comes from a subsequent paper, where it was noted that small millets made up less than 15% of the seed assemblage, and had a ubiquity of 36% (Weber & Kashyap 2013: fig. 2), and the authors also use to suggest that there was an increasing emphasis on millets and summer cultivation prior to the abandonment of the settlement (Weber & Kashyap 2013: 5). The crop assemblage at Farmana is clearly different to the assemblages from Rojdi and Babar Kot, and also that at Harappa.

At present there are no direct dates on crop seeds from Farmana, and although millets made up a statistically significant proportion of the assemblage, it is not possible to say anything more specific about the role of summer crops without the publication of the frequency and proportions of the entire assemblage. It is noteable, however, that rice does not appear to have played a major role in the subsistence economy at Farmana (Weber *et al*. 2011: 813).

The differences between the crop proportions at Mohenjo daro, Harappa, Rojdi, Babar Kot, Farmana and those seen at Masudpur VII and Masudpur I presented here serve to highlight the variability of Indus farming practices. Farmers in different regions appear to have practiced variations of single and two season cropping using different combinations of crops, which emphasises the importance of using nuanced terminology to describe their practices (cf Petrie & Bates in press).

SI.3. Plant species

The geographical origin of millet, rice, mung bean, urad bean and horsegram in South Asia

The geographic origin of specific plant species attested at Indus settlements has been much discussed. The most commonly attested winter species, including wheat (*Triticum* sp.) and barley (*Hordeum vulgare*) were likely domesticated in West Asia and then adopted by populations in South Asia (Fuller 2011; Kingwell-Banham & Fuller 2012; Kingwell-Banham *et al*. 2015; Petrie 2015). It is also evident that several summer crops were also imported into South Asia, including broomcorn, foxtail, finger and pearl millet (*Panicum miliaceum*, *Setaria italica*, *Eleusine coracana*, *Pennisetum glaucum* respectively; Fuller 2011; Kingwell-Banham *et al*. 2015). There are, however, a number of summer crop species that originated locally in South Asia, including a species of rice (*Oryza* sp.), several millet species (*Setaria verticillata*, *Setaria pumila*, *Brachiaria ramosa*, and *Echinochloa colona*), and a number of tropical pulses (mung bean [*Vigna radiata*], urad bean [*Vigna mungo*], and horsegram [*Macrotyloma uniflorum*]).

There is debate, however, about the specific regions within South Asia in which each of these species was first brought under cultivation, which has some bearing on the date at which each was adopted by Indus populations. Although the known wild progenitors come from elsewhere in South Asia, the earliest attestations of rice, several millets, (*Setaria pumila*, *Echinochloa* *colona*), mung bean, urad bean, and horsegram at Indus settlements, have all come from northwest India (Saraswat *et al*. 2000; Saraswat 2002; Saraswat & Pokharia 2002, 2003; Fuller & Harvey 2006; Fuller 2011; Fuller & Murphy 2014). The early dates for the exploitation of rice in the Middle Ganges (Tewari *et al*. 2008), indicated that it was likely a cultivar imported from that region into north-west India. However, the proposed early dates for the attestations of the pulses and millets in northwest India have lead Fuller (2011: S358; also Fuller & Murphy 2014) to suggest that they might have been brought into cultivation there independently from wild populations.

Rice

There has been considerable discussion of the cultivation and domestication of rice in South Asia, and the exact location and dates at which the earliest cultivation of rice in South Asia is debated, involving discussion of both genetic and archaeological evidence. Genetic evidence suggests that the South Asian form of fully domesticated rice, *Oryza sativa* ssp. *indica*, was hybridised from the Chinese rice *Oryza sativa* ssp. *japonica*, and a semi-domesticated Indian rice, which is currently referred to as proto-indica (Fuller 2005, 2006, 2011; Castillo *et al*. 2015). This hybridisation was not a simple, single event, but appears to have involved multiple instances of back-crossing between the semi-domesticated proto-indica and *Oryza sativa* ssp. *japonica* (Castillo *et al*. 2015). It also took place after a prolonged period of human interaction with the wild *Oryza nivara*, which resulted in the semi-domesticated proto-indica form (Castillo *et al*. 2015). It is notable that wild *Oryza nivara* is a perennial that prefers drier conditions than the Chinese *Oryza sativa* ssp. *japonica* (Weisskopf *et al*. 2013). Today it is found in the Ganges basin, and it is therefore conceivable that part of the cultivation/domestication process occurred there, but Fuller (2011: 82; also Fuller & Madella 2002) has suggested that the independent rice agricultural tradition of the Indo-Gangetic region, which includes the interfluve between the Indus and Ganges, “never […] proceeded on its own to full domestication” until the arrival of *O. sativa* ssp. *japonica c*. 2000BC.

It has been proposed that there is evidence for the exploitation of domesticated rice in the Central Ganges valley by the seventh millennium BC (Tewari *et al*. 2008), though it has also been argued that this is actually evidence for the cultivation of wild strands (Fuller 2011). The debate about the domestication of rice in South Asia is complicated by the lack of systematic flotation at settlements where rice has been attested. It has been maintained that rice domestication cannot be assessed from the grain alone, but rather requires the analysis of spikelet bases (Thompson 1996; Harvey 2006), which are only recovered through flotation. While it is acknowledged that rice was being cultivated in the central Ganges Valley from as early as the seventh millennium BC (Tewari *et al*. 2005/06, 2008; Fuller 2011; Kingwell-Banham *et al*. 2015), there is a gap between the first evidence for the cultivation of wild rice stands at Lahuradewa *c*. 8000–6000BC (Tewari *et al*. 2008) and the evidence for the exploitation of fully domesticated rice at Senuwar 2 (Saraswat 2004/05) and Mahagara by *c*. 1800–1600BC (Fuller *et al*. 2010).

Some evidence for rice cultivation by Indus populations has been put forward to fill this chronological gap, but problems with the dating and nature of this evidence has led to Indus rice use becoming a controversial topic. Initial attestations of rice cultivation from excavations at Indus settlements relied on the identification of rice impressions in building material (e.g. Ghosh & Lal 1963), but most of these instances have now been discounted (Vishnu-Mittre & Savithri 1975). Subsequently Fujiwara *et al*. (1992; Fujiwara 1993; also Weber 2003) reported rice phytoliths from Mature Harappan deposits at Harappa, but these contexts were not securely dated. However, Madella (2003; also Fuller & Madella 2002) has confirmed the presence of rice phytoliths, including husk double peaks, at Harappa *c*. 2200BC, confirming this attestation. Weber (1999: 819) has somewhat opaquely stated that “a few carbonized rice grains have been recovered from each occupation at Harappa”, but the only stratigraphically secure examples come from Late Harappan contexts, which date after *c*. 1900 BC (Weber 2003).

More recently, rice grains have been reported at Banawali, Balu and Kunal in north-west India (Saraswat *et al*. 2000; Saraswat 2002; Saraswat & Pokharia 2002, 2003; see Fuller & Harvey 2006; Fuller 2011; Fuller & Murphy 2014). However, as noted in the main text, direct dating of wheat grains from Banawali and Kunal have produced very late dates (Liu *et al*. 2016). Furthermore, the stratigraphic sequence of Balu, and thus the context of the samples, has not been published in any detail, and the dating of the rice grains is unclear. The problems with the chronology are emphasised by the fact that the Early and Mature Harappan periods of occupation have been given a date range of *c*. 2300–1700 BC (Saraswat 2002: 198; Saraswat & Pokharia 2002: 153–54), which overlaps with the acknowledged date span of the Mature and Late Harappan periods (Table S1). Other attestations of rice at Indus settlements have generally tended to be isolated to sites with low cereal species variability (e.g. Weber 1992). As noted in the main paper, it has been argued that rice was not an important crop for Indus populations until the Late Harappan and even post-Harappan period; i.e. after the arrival of *Oryza sativa* ssp. *japonica* from China (Fuller & Madella 2002: 336–37; Fuller & Qin 2009).

Debates over the intensity of Indus rice use aside, the domesticated status of the rice grains at Indus sites has not previously been addressed directly. Bates *et al*. (forthcoming) have, however, presented new data on spikelet bases from the *Land, Water, Settlement* project excavations that suggest that the northeast of the Indus region in northwest India may have been part of the long process of rice domestication in South Asia, resulting in what has been termed proto-indica semi-domesticated rice. The importance of pinning down the date of Indus rice use becomes imperative for placing it within the trajectory of rice domestication in South Asia more broadly, to ascertain whether rice was being exploited in northwest India before or after the hypothesised arrival of Chinese *Oryza sativa* ssp. *Japonica*, and to confirm its use by Indus populations.

Millets

Millets are a vast group of forage grasses with small, coarse grains that are not necessarily related to one another (Weber 1991; Pokharia *et al*. 2014). In total, there are nine major genera of millets and they have three areas of origin—Africa, China, and South Asia (Weber & Fuller 2008/09). Although they only comprise 1% of the current agricultural strategies of South Asia (Weber & Fuller 2008/09), millets are still essential crops in some regions because of their drought tolerance.

The focus of archaeological interest in millets has been biased towards the larger grained varieties (Fuller 2002; Weber & Fuller 2008/09; Weber & Kashyap 2013), and in South Asian archaeology this has led to an interest in the arrival of African and Chinese millets in the Indus region (e.g.: Meadow 1989, 1996, 1998). This focus may be an artefact of the sampling strategies and the lack of systematic flotation in South Asian archaeobotany, or a tendency to automatically identify all small millets as *Eleusine* sp. (Fuller & Madella 2002), and thus to assume that there was a lack of variety before the arrival of non-native species to the region. However, a number of small millet species have wild progenitors in the Southern Deccan, Orissa and Saurashtra, including *Setaria verticillata, Setaria pumila, Brachiaria ramosa,* and *Echinochloa colona* (Fuller 2002, 2003, 2011; Fuller & Madella 2002; Weber & Fuller 2008/09; Weber & Kashyap 2013), and these were potentially utilised in the Indus region. This possibility is evidenced by finds of native *Setaria* sp. at sites such as Babar Kot (Reddy 1997) and Rojdi (Weber 1989) in Gujarat. *Setaria glauca,* and *Setaria viridis* have also been reported from Early

Harappan Babar Kot (Reddy 1997), *Setaria glauca*, *Setaria tormentosa*, and *Setaria* sp. have been reported at Harappa A period Rojdi (Weber 1989), while *Setaria* sp. has been reported from Early Harappan levels at Banawali in northwest India (Saraswat *et al*. 2000; Saraswat & Pokharia 2002; Fuller 2011: S358). *Echinochloa* sp. has been found at Indus settlements such as Mature Harappan period Surkotada in Gujarat (Vishnu Mittre 1990: 388–91), while *Echinochloa crus-galli* has been attested at Shortugai, which is an Indus outpost settlement in northern Afghanistan (Willcox 1989, 1991, 1992; Fuller 2011: S358). The specific identification of small grained millet is, however, notoriously difficult, so potentially some of these genus and species attributions are in need of revision (Fuller 2002).

The detection of small native millets at Indus settlements indicates that these species may have been overlooked in many discussions of Indus agricultural strategies, where priority has typically been given to the larger grained cereals. The importance of small grained millets to Indus agriculture has, nonetheless been increasingly recognised (Weber & Fuller 2008; Weber & Kashyap 2013). For example, based on preliminary data from Farmana and the analysis of Rojdi, Weber and Kashyap (2013) have argued that small millets were common to Indus agriculture and postulated that the marginalisation of millet as a famine crop is only a recent development, occurring as a result of agricultural mechanisation. Small, native millets have the potential to be viewed as an important crop for Indus peoples based on their suitability to the varied environment inhabited by the Indus populations. They can be also grown in an alternate season and can thus be used to expand agricultural strategies. Although millets have now been identified at a number of settlements, accurate dating is essential to understand where and when particular species were first exploited by Indus populations.

Tropical pulses

There are a number of pulses native to the subcontinent, including *Macrotyloma uniflorum* (horsegram) and several of the *Vigna* species such as mung bean (*Vigna radiata*) and urad bean (*Vigna mungo*). Although it has been asserted that these crops were not exploited by Indus populations until the Late Harappan period or later (Fuller 2002, 2006; Fuller & Madella 2002; Fuller & Harvey 2006), there have been earlier attestations at several sites.

Vigna radiata and *Vigna mungo* are tropical/sub-tropical pulses native to the forest-savannah margins of South Asia (Fuller & Madella 2002; Fuller & Harvey 2006). Wild *Vigna radiata* is found in the Western Himalayan foothills and the Eastern Ghats (Fuller 2006, 2011) and Fuller and Harvey (2006) have suggested that there were two domestication areas, one in south India and the other in the upper Ganges. Wild *Vigna mungo* can be found in the northernmost parts of the Western Ghats, in Gujarat and Rajasthan (Fuller 2006), and also has two probable domestication areas, Saurashtra and the Middle Ganges (Fuller & Harvey 2006). Fuller and Harvey (2006) and Fuller (2011) have postulated that the Indo-Gangetic region and even the Eastern Harappan sites such as Kunal and Balu may have been important in the domestication history of both *Vigna* species and that there may have been pre-Harappan cultivation in the eastern Indus civilisation region (Saraswat 2002; Saraswat & Pokharia 2002, 2003; see Fuller & Harvey 2006; Fuller 2011; Fuller & Murphy 2014). Secure evidence from the Early Harappan period is, however, lacking (Fuller 2011).

Although horsegram is native to South Asia, it is uncertain where on the subcontinent it originated and was domesticated (Fuller & Madella 2002; Fuller & Harvey 2006). Suggestions that it was a savannah, semi-arid zone plant have been put forward, as has the possibility of a peninsular origin (Fuller 2006; Fuller & Harvey 2006). The presence of horsegram in the Mature Harappan period at sites such as Banawali (Saraswat *et al*. 2000) and Balu (Saraswat 2002; Saraswat *et al*. 2003) has led Fuller (2006, 2011; Fuller & Murphy 2014) to suggest that one of the domestication locations might have been the Indo-Gangetic divide.

Given the lack of secure dating and the debates surrounding the spread and use of these pulses in prehistory, the radiocarbon dating of tropical pulses at Indus sites is essential to understanding the development of pulse agriculture in South Asia.

SI.4. Excavations and samples

Masudpur VII

In Table S2, percentages are shown as proportion of total crop assemblage by context. Other crop elements such as oilseed, fiber crops, fruits and crops that could not be identified beyond family level are not included, and as such the total percentages shown here will not add to 100%.

Table S2. Cereal grains identified in sampled contexts at Masudpur VII (Bhim Wada Jodha). Contexts and species that have been subjected to radiocarbon dating are shaded.

No.	Type	Wheat (*Triticum* sp.)[1]	Barley (*Hordeum vulgare*)[1]	Rice (*Oryza* sp.)	Millets (*Setaria* sp., *Echinochloa* sp.)[2]	Winter pulses [3]	Summer pulses[4]
405	Surface						
406	Fill						
407	Fill						
409	Collapse						
415	Ash fill	42.86%	(57.14%)				
418	Collapse				(100.00%)		
410	Fill					100.00%	
414	Pit fill						
419	Fill	(25.00%)	(25.00%)		25.00%		25.00%
422	Fill				50.00%		
423	Pit fill	7.69%			76.92		
425	Fill				60.00%		
428	Pit fill	2.56%	43.59%	2.56%		2.56%	41.03%
429	Pit fill	(2.44%)	7.32%	2.44%	39.02%	4.88%	12.20%
426	Fill	[5]	[5]				
430	Fill	(26.09%)	17.39%		39.13%	4.35%	4.35%
508	Collapse	(2.22%)	(2.22%)			(2.22%)	(2.22%)
513	Fill	(6.67%)	6.67%		20.00%		26.67%
514	Collapse				60.00%		20.00%
515	Fill	6.25%	2.08%%	6.25%	41.67%	6.25%	12.50%
517	Fill	(30.77%)	(30.77%)	15.38%			30.77%
522	Ash fill		14.29%		28.57%	14.29%	14.29%
525	Fill	10%			80.00%		
526	Fill				87.50%		
527	Fill				(66.67%)	33.33%	
Average[6] %		3.25%	8.77%	2.27%	32.47%	3.25%	12.99%
Ubiquity[7]		20.00%	24.00%	16.00%	56.00%	28.00%	36.00%

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[1] Numbers shown in brackets refer to *Hordeum/Triticum*—i.e. large grained cereal fragments that could not be confidently assigned to either *Hordeum vulgare* or *Triticum* sp.

[2] Numbers shown in brackets refer to SEB (*Setaria, Echinochloa* or *Brachiaria*)—a group of small grained hulled millets with long embryos, which includes *Echinochloa* sp. and *Setaria* sp., but which could not be identified further due to preservation conditions.

[3] Winter pulses include *Pisum* sp., *Lens* cf. *culinaris*, *Cicer* sp., *Vicia/Lathyrus*, *Lathyrus* sp. Numbers shown in brackets refer to Big Fabaceae—a reference to a large pulse fragment that could not be confidently assigned to any genera of pulse due to preservation conditions and could therefore be either a summer or winter pulse species.

[4] Summer pulses include *Vigna radiata*, *Vigna mungo*, *Vigna acconitifolia*, *Vigna* cf. *trilobata*, *Macrotyloma* cf. *uniflorum*

[5] None of the archaeobotanical material from this context was attributable to species, see Table S5.

[6] Of site assemblage as whole (not of percentages).

[7] Percentage of contexts a species/crop group was present in.

Masudpur I

In Table S3 below, percentages are shown as proportion of total crop assemblage by context. Other crop elements such as oilseed, fiber crops, fruits and crops that could not be identified beyond family level are not included, and as such the total percentages shown here will not add to 100%.

Table S3. Cereal grains identified in sampled contexts at Masudpur I (Sampolia Khera). Contexts and species that have been subjected to radiocarbon dating are shaded.

No.	Type	Wheat (*Triticum* sp.)[8]	Barley (*Hordeum vulgare*)[1]	Rice (*Oryza* sp.)	Millets (*Setaria* sp., *Echinochloa* sp.)[9]	Winter pulses [10]	Summer pulses[11]
109	Fill			14.29%	28.57%		28.57%
110	Fill	(5.00%)	(5.00%)		50.00%	(10.00%)	(10.00%)
111	Pit fill		4.76%		85.71%		
113	Fill	(6.67%)	6.67%	13.33%	26.67%	13.33%	13.33%
114	Pit fill	50.00%					
115	Pit fill	5.08%	18.64%	1.69%	42.37%		5.08%
116	Pit fill	(20.00%)	50.00%				10.00%
119	Pit fill	(4.00%)	(4.00%)	4.00%	76.00%		4.00%
120	Collapse	(15.63%)	9.38%		53.13%	3.13%	6.25%
121	Pit fill	(66.67%)	(66.67%)			33.33%	
125	Ash fill	6.79%	36.65%	1.36%	25.79%		5.43%
126	Fill	(15.38%)	19.32%		26.92%		19.23%
128	Fill	5.77%	30.77%	1.92%	19.23%	3.85%	15.38%
129	Pit fill	(11.54%)	(11.54%)	3.85%	61.54%		15.38%
130	Pit fill	7.14%	21.43%		35.71%	(7.14%)	7.14%
132	Pit fill	(16.67%)	(16.67%)		33.33%	16.67%	
134	Surface	(23.40%)	24.47%		38.30%		0.35%
135	Pit fill	11.76%	35.29%		29.41%		5.88%
137	Pit fill	5.15%	58.76%	2.06%	7.22%		4.12%
302	Collapse				66.67%		33.33%
303	Collapse						
304	Ash fill	(38.46%)	(38.46%)		38.46%		7.69%
305	Fill			5.00%	65.00%	5.00%	5.00%
308	Fill	(35.71%)	(35.71%)	2.38%	50.00%	(2.38%)	9.52%
310	Fill	2.70%	6.76%	2.70%	72.97%	2.70%	6.76%
314	Pit fill	2.56%	3.42%	2.56%	70.09%	1.71%	11.97%
317	Fill	(0.98%)	4.90%	8.82%	73.53%	1.96%	7.84%
319	Pit fill	0.60%	8.80%	13.80%	63.80%	1.90%	5.60%
323	Pit fill	0.24%	6.16%	40.32%	48.00%	0.48%	0.32%
321	Pit fill	5.57%	43.61%	3.93%	27.21%		5.57%
Average[12] %		1.85%	16.42%	18.75%	44.65%	0.76%	4.37%
Ubiquity[13]		40.00%	60.00%	53.33%	86.67%	36.67%	83.33%

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[8] Numbers shown in brackets refer to *Hordeum/Triticum*—i.e. large grained cereal fragments that could not be confidently assigned to either *Hordeum vulgare* or *Triticum* sp.

[9] Numbers shown in brackets refers to SEB (*Setaria, Echinochloa* or *Brachiaria*)—a group of small grained hulled millets with long embryos, which includes *Echinochloa* sp. and *Setaria* sp., but which could not be identified further due to preservation conditions.

[10] Winter pulses include *Pisum* sp., *Lens* cf. *culinaris*, *Cicer* sp., *Vicia/Lathyrus*, *Lathyrus* sp. Numbers shown in brackets refers to Big Fabaceae—a reference to a large pulse fragment that could not be confidently assigned to any genera of pulse due to preservation conditions and could therefore be either a summer or winter pulse species.

[11] Summer pulses include *Vigna radiata, Vigna mungo, Vigna acconitifolia, Vigna* cf. *trilobata, Macrotyloma* cf. *uniflorum*

[12] Of site assemblage as whole (not of percentages).

[13] Percentage of contexts a species/crop group was present in.

SI.5. Radiocarbon dating

ORAU Protocols

The chemical pretreatment protocols used by the Oxford Radiocarbon Accelerator Unit (ORAU) were updated in 2010 (Brock *et al*. 2010). These routine pretreatments are designed to remove contaminating substances such as humic acids from the material to be dated. As noted in the published protocol, the specific pre-treatment used is dependent upon the main macromolecular component of the sample (e.g. collagen containing materials, charcoal and charred material), and the strength of treatment for each component group can vary depending upon the fragility of the sample material (Brock *et al*. 2010). The initial batch of carbonised seed grain samples from Masudpur VII and Masudpur I was subjected to a standard acid-base-acid (ABA) pre-treatment to remove contaminants.

There was high rate of failure resulting from the ABA pre-treatments applied to charred grains from Masudpur VII and Masudpur I. This suggests one of two alternative explanations. First, that the samples have been affected by significant proportions of contaminating humic acids which, when removed from the samples by alkaline treatment, result in no autochthonous carbon remaining. Second, that the samples are of a fragile nature due to the arid and warm conditions they have experienced post-depositionally, and when treated with alkali in the ABA protocol they enter solution as a function of self-humification, resulting in no remaining dateable carbon. Given the arid and dry conditions of these sites and the lack of active soil horizons it is probably not likely that mobile humic complexes are present, and therefore the second alternative appears more likely. We have to assume that there might be contamination, however, and in the light of this we treated all samples with the most suitable chemical pre-treatment method. In future it might be possible to test the need for strong ABA treatment by comparing it against a less rigorous method to see whether there is any age offset. The analytical data associated with the successfully dated samples is shown in Table S8.

Samples submitted for analysis

Table S4. Charred cereal grain samples from Masudpur VII (Bhim Wada Jodha) submitted for AMS radiocarbon dating, ordered by site and thence by context number.

Trench	Context	Samples	Type	Result
YA2	405	1 x small seed indet., 11 x parenchyma	mixed	yield
YA2	410	1 x frag. of *Vicia*/*Lathyrus*	legume vetch	yield*
YA2	415	3 x *Triticum* sp., 4 x cf. cereal grain	wheat	yield
YA2	418	1 x small Fabaceae indet	bean	no yield
YA2	423	1 x *Triticum* sp.	wheat	yield
YA2	426	9 x small seeds indet., 3 x med seeds indet., 1 x grass indet.	mixed	yield
YA2	428	1 x frag. of *Vicia*/*Lathyrus*	legume vetch	yield
YA2	429	2 x *Macrotyloma* sp.	pulse	yield
YA2	430	3 x frag. of *Vicia*/*Lathyrus*	pulse	no yield
YB1	508	1 x large Fabaceae indet.	bean	no yield
YB1	513	5 x *Vigna mungo*	bean black	yield
YB1	513	1 x *Macrotyloma* sp. 3 x *Ziziphus*	mixed	no yield
YB1	514	2 x *Vigna radiata*	bean moong	yield
YB1	515	18 x *Echinochloa* sp.	millet	yield
YB1	515	3 x *Triticum* sp. frags	wheat	no yield
YB1	515	4 x *Oryza* sp.	rice	no yield
YB1	515	2 x *Macrotyloma* sp.	pulse	no yield
YB1	517	4 x *Oryza* sp.	rice	yield
YB1	517	2 x *Triticum* sp.	wheat	no yield
YB1	517	4 x *Ziziphus* fragments	fruit	no yield
YB1	522	1 x *Pisum*, 2 x *Vigna,* 1 x *Ziziphus*	mixed	yield
YB1	525	18 x *Echinochloa* sp.	millet	yield
YB1	525	2 x *Triticum* sp. Indet.	wheat	no yield
YB1	527	2 x frags of *Vicia*/*Lathyrus*	legume vetch	yield

* This sample was analysed twice.

Table S5. Charred cereal grain samples from Masudpur I (Sampolia Khera) submitted for AMS radiocarbon dating, ordered by context number.

Trench	Context	Samples	Type	Result
XA1	110	1 x medium Fabaceae indet	bean	yield
XA1	113	1 x frag. of *Vicia*/*Lathyrus*	legume vetch	yield
XA1	114	1 x *Triticum* sp., 12 x frags small seeds indet	wheat	yield
XA1	121	2 x cf. cereal grain, 1 x frag of *Vicia*/*Lathyrus*, 4 x grass seed indet.	mixed	yield
XA1	128	3 x *Triticum* sp.	wheat	yield
XA1	130	1 x cf. *Triticum* sp., 3 x med Fabaceae indet., 1 x med seed indet., 1 x sedge indet.	mixed	yield
XA1	134	2 x *Macrotyloma* sp.	pulse	no yield
XA1	137	3 x *Triticum* sp.	wheat	no yield
XA1	137	3 x *Oryza* sp.	rice	no yield
XA1	137	3 x *Vigna mungo*	bean black	no yield
XM2	308	5 x small Fabaceae indet.	bean	yield
XM2	310	1 x *Triticum* sp., 1 x frag. *Triticum* sp., 4 x frag. *Oryza* sp. 2 x frag. *Vicia*/*Lathyrus*	mixed	yield
XM2	314	2 x fragment of *Vicia*/*Lathyrus*	legume vetch	yield
XM2	319	30 x *Echinochloa* sp.	millet	yield
XM2	319	1 x *Macrotyloma* sp.	pulse	no yield
XM2	319	1 x *Vigna radiata*	bean moong	no yield
XM2	321	3 x *Oryza* sp.	rice	yield
XM2	321	2 x *Triticum* sp.	wheat	yield
XM2	321	1 x *Vigna mungo*	bean black	no yield
XM2	323	2 x *Triticum* sp.	wheat	yield
XM2	323	2 x *Oryza* sp.	rice	no yield
XM2	323	35 x *Echinochloa* sp.	millet	no yield
XM2	323	30 x *Setaria* sp.	millet	no yield
XM2	323	2 x *Vigna radiata*	bean moong	no yield

Table S6. AMS radiocarbon results obtained from the samples selected from Masudpur VII (Bhim Wada Jodha), by trench, in stratigraphic order.

Trench	Context	OxA	BP	Std/Dev	cal BC		Prob.	$\delta^{13}C$	Type	Period	Comment
MSDVII	527	OxA-24734	4158	30	2879	2631	95.4	-23.17	*Vicia*/*Lathyrus*	Early	
MSDVII	525	OxA-28837	4178	33	2887	2637	95.3	-9.66	*Echinochloa* sp.	Early	
MSDVII	522	OxA-26557	1961	27	AD 40	118	95.4	-20.86	mixed	E Historic	intrusive
MSDVII	514	OxA-28660	1612	27	AD 393	536	95.4	-22.99	*Vigna radiata*	E Historic	intrusive
MSDVII	513	OxA-28835	3620	45	2135	1883	95.4	-23.88	*Vigna mungo*	L Mature	
MSDVII	517	OxA-28661	3475	30	1886	1695	95.4	-25.56	*Oryza* sp.	Late	
MSDVII	515	OxA-28836	3536	35	1958	1751	95.4	-9.23	*Echinochloa* sp.	Late	
MSDVII	426	OxA-24892	4142	34	2876	2620	95.4	-23.29	mixed	Early	
MSDVII	429	OxA-28659	4003	31	2581	2466	95.4	-24.68	*Macrotyloma* sp.	Early/Mature	
MSDVII	428	OxA-24893	4011	32	2618	2468	95.3	-22.38	*Vicia*/*Lathyrus*	Early/Mature	
MSDVII	423	OxA-24891	3963	36	2575	2346	95.4	-24.99	*Triticum* sp.	E Mature	
MSDVII	415	OxA-24719	3932	32	2561	2305	95.3	-23.65	*Triticum* sp.	E Mature	
MSDVII	410	OxA-24718	3942	31	2566	2310	95.4	-22.79	*Vicia*/*Lathyrus*	E Mature	
MSDVII	410	OxA-24733	4080	37	2861	2491	95.4	-23.05	*Vicia*/*Lathyrus*	E Mature	problematic*
MSDVII	405	OxA-24717	2761	29	994	831	95.4	-23.8	mixed	PGW	intrusive

* This sample was analysed twice. The second analysis is different from the first, though the reasons for this are unclear.

Table S7. AMS radiocarbon results obtained from the samples selected from Masudpur I (Sampolia Khera), in stratigraphic order.

Trench	Context	OxA	BP	Std/Dev	cal BC		Prob.	δ^{13}C	Type	Period	Comment
MSDI	130	OxA-24729	3711	29	2200	2027	95.4	-23.09	mixed	L Mature	intrusive?
MSDI	128	OxA-24728	3761	29	2287	2045	95.4	-23.72	*Triticum* sp.	E/M Mature	
MSDI	121	OxA-24727	3810	29	2397	2141	95.4	-21.99	mixed	E Mature	
MSDI	113	OxA-24726	3789	30	2335	2135	95.4	-22.76	*Vicia*/*Lathyrus*	E Mature	
MSDI	110	OxA-24725	3813	30	2290	2030	95.4	-23.62	Fabaceae indet.	M Mature	
MSDI	114	OxA-X-2423-34	3998	37	2621	2459	95.4	-23.12	*Triticum* sp.	–	inaccurate*
MSDI	321	OxA-28663	3813	32	2431	2141	95.5	-24.72	*Oryza* sp.	E Mature	
MSDI	321	OxA-24732	3786	30	2333	2063	95.4	-24	*Triticum* sp.	E Mature	
MSDI	323	OxA-24716	3756	34	2287	2040	95.4	-24.1	*Triticum* sp.	M Mature	
MSDI	319	OxA-28662	3745	30	2279	2036	95.3	-8.46	*Echinochloa* sp.	M Mature	
MSDI	310	OxA-24730	3702	28	2198	1984	95.4	-23	mixed	L Mature	
MSDI	308	OxA-X-2423-35	3850	38	2459	2206	95.4	-24.65	Fabaceae indet.	–	inaccurate*
MSDI	314	OxA-24731	3594	28	2025	1888	95.4	-23.89	*Vicia*/*Lathyrus*	L Mature	

* This sample produced an offset between the δ^{13}C measurements on the AMS and the mass spectrometer, which provides the possibility on an inaccurate date, therefore it should be considered with caution, and it has been given an OxA-X prefixed result.

Table S8. AMS radiocarbon results and analytical data collected at the ORAU. Single entities were AMS dated. We would expect ~65% carbon on combustion from the treated samples.

OxA/OxA-X	Used (mg)	Yield (mg)	%Yld	%C	δ^{13}C (per mille)
2423-34	16.39	1.1	6.7	68.5	-23.1
2423-35	7.08	0.96	13.6	63.9	-24.7
24716	13.27	1.07	8.1	65.1	-24.1
24717	11.49	1.56	13.6	67.2	-23.8
24718	9.2	2.36	25.7	67	-22.8
24719	4.64	1.23	26.5	68.2	-23.6
24725	16.9	4.05	24	62	-23.6
24726	28.05	22.05	78.6	66.1	-22.8
24727	17.17	6.06	35.3	64.1	-22.0
24728	9.83	5.04	51.3	65.3	-23.7
24729	7.97	3.21	40.3	63.8	-23.1
24730	7.42	3.21	43.3	62.6	-23.0
24731	11.56	6.63	57.4	69	-23.9
24732	11.32	4.43	39.1	62.5	-24.0
24733	8.31	4.58	55.1	64.7	-23.0
24734	10.1	2.7	26.7	67.6	-23.2
24891	15.4	0.9	5.8	64.6	-25.0
24892	12.7	2.2	17.3	60.3	-23.3
24893	18.4	2	10.9	68.9	-22.4
26557	5.97	4.69	78.6	61	-20.9
28659	8.77	1.58	18	53.6	-24.7
28660	4.56	1.15	25.2	67.1	-23.0
28661	3.0	1.38	46	65.3	-25.6
28662	9.84	1.39	14.1	63.1	-8.5
28663	4.35	1.93	44.4	59.9	-24.7
28835	10.58	0.89	8.4	67.3	-23.9
28836	3.8	0.78	20.5	66.2	-9.2
28837	3.09	0.89	28.8	69.4	-9.7

References (main text)

AGRAWAL, D.P. 2007. *The Indus civilisation: an interdisciplinary perspective*. Delhi: Aryan.

BATES, J. 2016. Social organization and change in Bronze Age South Asia: a multi-proxy approach to urbanisation, de-urbanisation and village life through phytolith and macrobotanical analysis. Unpublished PhD dissertation, University of Cambridge.

BATES, J., C.A. PETRIE & R.N. SINGH. Forthcoming. Approaching rice domestication in South Asia: new evidence from Indus settlements in northern India. *Journal of Archaeological Science*.

– Submitted. Cereals, calories and change: exploring approaches to quantification in Indus archaeobotany. *Archaeological and Anthropological Science*.

BATES, J., R.N. SINGH & C.A. PETRIE. 2016. Exploring Indus crop processing: combining phytoliths and macrobotanical analysis to consider the organisation of agriculture in northwest India c. 3200–1500 BC. *Vegetation History and Archaeobotany* (special issue) [published online 21 May 2016; DOI 10.1007/s00334-016-0576-9].

CHAKRABARTI, D.K. 1988. *Theoretical issues in Indian archaeology*. Delhi: Munshiram Manoharlal.

– 1999. *India: an archaeological history, Palaeolithic beginnings to Early Historic foundations*. Delhi: Oxford University Press.

FULLER, D.Q. 2002. Fifty years of archaeobotanical studies in India: laying a solid foundation, in S. Settar & R. Korisettar (ed.) *Indian archaeology in retrospect III: archaeology and interactive disciplines*: 247–364. Delhi: Manohar.

– 2006. Agricultural origins and frontiers in South Asia: a working synthesis. *Journal of World Prehistory* 20: 1–86. doi:10.1007/s10963-006-9006-8

– 2011. Finding plant domestication in the Indian subcontinent. *Current Anthropology* 52.S4: S347–S362.

FULLER, D.Q. *et al*. 2010. Consilience of genetics and archaeobotany in the entangled history of rice. *Archaeological and Anthropological Sciences* 2: 115–31.

FULLER, D.Q. & M. MADELLA. 2002. Issues in Harappan archaeobotany: retrospect and prospect, in S. Settar & R. Korisettar (ed.) *Indian archaeology in retrospect II: protohistory*: 317–90. Delhi: Manohar.

FULLER, D.Q. & C. MURPHY. 2014. Overlooked but not forgotten: India as a center for agricultural domestication. *General Anthropology* 21.2: 1–8.

FULLER, D.Q. & L. QIN. 2009. Water management and labour in the origins and dispersal of Asian rice. *World Archaeology* 41: 88–111. doi:10.1080/00438240802668321

JOSHI, J.P., M. BALA & J. RAM. 1984. The Indus civilisation: a reconsideration on the basis of distribution maps, in B.B. Lal & S.P. Gupta (ed.) *Frontiers of the Indus civilisation*: 511–30. Delhi: Books and Books.

KASHYAP, A. & S.A. WEBER. 2010. Harappan plant use revealed by starch grains from Farmana, India. *Antiquity* (Project Gallery). http://antiquity.ac.uk/projgall/kashyap326/

KENOYER, J.M. 1998. *Ancient cities of the Indus Valley civilisation*. Karachi: Oxford University Press.

KINGWELL-BANHAM, E., C.A. PETRIE & D.Q. FULLER. 2015. Early agriculture in South Asia, in G. Barker & C. Goucher (ed.) *Cambridge world history, vol. II*: 261–288. Cambridge: Cambridge University Press.

KUMAR, M. 2009. Harappan settlements in the Ghaggar-Yamuna Divide. *Linguistics, Archaeology and the Human Past* 7: 1–76.

LAL, B.B. 1997. *The earliest civilisation of South Asia*. Delhi: Aryan.

LAWRENCE, D. & T.J. WILKINSON. 2015. Hubs and upstarts: pathways to urbanism in the northern Fertile Crescent. *Antiquity* 89: 318–44.

LIU, X., D.L. LISTER, Z. ZHAO, R.A. STAFF, P.J. JONES, L. ZHOU, C.A. PETRIE, J. BATES, A. PATHAK, T. PILGRAM & M.K. JONES. 2016. The virtues of small grain size: potential pathways to a distinguishing feature of Asian wheat. *Quaternary International* (special issue: Domestication East Asia [doi:10.1016/j.quaint.2016.02.059] [http://www.sciencedirect.com/science/article/pii/S104061821530197X].

MADELLA, M. 2014. Of crops and food: a social perspective on rice in the Indus civilisation, in M. MADELLA, C. LANCELOTTI & M. SAVARD (ed.) *Ancient plants and people: contemporary trends in archaeobotany*: 218–36. Tucson: University of Arizona Press.

MADELLA, M. & D.Q. FULLER. 2006. Palaeoecology and the Harappan civilisation of South Asia: a reconsideration. *Quaternary Science Reviews* 25.11–12: 1283–1301.

MEADOW, R.H. 1996. The origins and spread of agriculture and pastoralism in northwestern South Asia, in D. Harris (ed.) *The origins and spread of agriculture and pastoralism in Eurasia*: 390–412. London: UCL Press.

NATH, A. n.d. *Excavations at Rakhigarhi [1997–98 to 1999–2000]*. New Delhi: Archaeological Survey of India.

NATH, A., T. GARGE & R. LAW. 2014. Defining the economic space of Harappan Rakhigarhi: an interface of local subsistence mechanism and geologic provenience studies. *Puratattva* 44: 83–100.

Paleo-Labo AMS Dating Group. 2012. AMS radiocarbon dating, in J.S. Kharakwal, Y.S. Rawat & T. Osada (ed.) *Excavation at Kanmer 2005–06—2008–09*: 819–26. Kyoto: RIHN.

PETRIE, C.A. 2013. South Asia, in P. Clark (ed.) *The Oxford handbook of cities in world history*: 83–104. Oxford: Oxford University Press.

– In press. Crisis, what crisis? Adaptation, resilience and transformation in the Indus Civilisation, in J. Dreisen & T. Cunningham (ed.) *Crisis to collapse: the archaeology of social breakdown*. Louvain-la-Neuve: Aegis.

PETRIE, C.A. & J. BATES. In press. Double-cropping, multi-cropping and adaptation to variable environments in the Indus civilisation. *Journal of World Prehistory*.

PETRIE, C.A., R.N. SINGH & A.K. SINGH. 2009. Investigating changing settlement patterns on the plains: the 2009 survey and excavations at Masudpur (Hissar District, Haryana). *Puratattva* 39: 38–49.

PETRIE, C.A. R.N. SINGH, J. BATES, Y. DIXIT, C.A.I. FRENCH, D. HODELL, P.J. JONES, C. LANCELOTTI, F. LYNAM, S. NEOGI, A.K. PANDEY, D. PARIKH, V. PAWAR, D.I. REDHOUSE & D.P. SINGH. In press. Adaptation to variable environments, resilience to climate change: investigating *Land, Water and Settlement* in north-west India. *Current Anthropology*.

POKHARIA, A.K., J.S. KHARAKWAL, Y.S. RAWAT, T. OSADA, C.M. NAUTIYAL & A. SRIVASTAVA. 2011. Archaeobotany and archaeology at Kanmer, a Harappan site in Kachchh, Gujarat: evidence for adaptation in response to climatic variability. *Current Science* 100.12: 1833–46.

POKHARIA, A., J.S. KHARAKWAL & A. SRIVASTAVA. 2014. Archaebotanical evidence of millets in the Indian subcontinent with some observations on their role in the Indus civilisation. *Journal of Archaeological Science* 42: 442–55.

POSSEHL, G.L. 1982. The Harappan civilisation: a contemporary perspectiv, in G.L. Possehl (ed.) *Harappan civilisation: a contemporary perspective*: 15–28. Delhi: Oxford & IBH and the American Institute of Indian Studies.

– 1999. *Indus Age: the beginnings*. Philadelphia: University of Pennsylvania Press.

– 2002. *The Indus civilization: a contemporary perspective*. Walnut Creek (CA): AltaMira.

SARASWAT, K.S. 2002. Balu (29°40’ N; 76°22’ E), District Kaithal. *Indian Archaeology – A Review* 1996–7: 198–203.

– 2004/05. Agricultural background of the early farming communities in the Middle Ganga Plain. *Pragdhara* 15: 145–77.

SARASWAT, K.S. & A.K. POKHARIA. 2002. Harappan plant economy at ancient Balu, Haryana. *Pragdhara* 12: 153–71.

– 2003. Palaeoethnobotanical investigations at Early Harappan Kunal. *Pragdhara* 13: 105–39.

SARASWAT, K.S., C. SRIVASTAVA & A.K. POKHARIA. 2000. Palaeobotanical and pollen analytical investigations. *Indian Archaeology – A Review 1994–5*: 96.

SINGH, R.N., C.A. PETRIE, C.A.I. FRENCH, A.S. GOUDIE, S. GUPTA, R. TEWARI, A.K. SINGH, R. SRIVASTAVA, S. YADAV & V.K. SINGH. 2008. Settlements in context: reconnaissance in western Uttar Pradesh and Haryana, April and May 2008. *Man and Environment* 33: 71–87.

SINGH, R.N. & C.A. PETRIE. 2009. Lost rivers and life on the plains – approaches to understanding human/environment interaction between the collapse of Indus urbanism and the rise of the Early Historic cities (The Land, Water and Settlement Project), in *Sarasvati River—a perspective*: 102–11. Kurukshetra: Kurukshetra University.

SINGH, R.N., C.A. PETRIE, V. PAWAR, A.K. PANDEY, S. NEOGI, M. SINGH, A.K. SINGH, D. PARIKH & C. LANCELOTTI. 2010. Changing patterns of settlement in the rise and fall of Harappan urbanism: preliminary report on the Rakhigarhi Hinterland Survey 2009. *Man and Environment* 35: 37–53.

SURAJ BHAN. 1975. *Excavation at Mitathal and Other Explorations in the Sutlej-Yamuna Divide*. Kurukshetra: Kurukshetra University.

TEWARI, R., K.S. SRIVASTAVA, I.B. SARASWAT & K. SINGH. 2008/09. Early farming at Lahuradewa. *Pragdhara* 19: 347–73.

VISHNU-MITTRE & SAVITHRI, R. 1982. Food economy of the Harappans, in G.L. Possehl (ed.) *Harappan civilisation*: 205–21. Warminster: Aris and Philips.

WEBER, S.A. 1991. *Plants and Harappan subsistence: an example of stability and change from Rojdi*. New Delhi: Oxford and IBH.

– 1999. Seeds of urbanism: palaeoethnobotany and the Indus Civilisation. *Antiquity* 73: 813-26.

– 2003. Archaeobotany at Harappa: indications for change, in S.A. Weber & B. Belcher (ed.) *Indus ethnobiology*: 175–98. Lexington (KY): Lanham.

WEBER, S.A., T. BARELA & H. LEHMAN. 2010. Ecological continuity: an explanation for agricultural diversity in the Indus Civilisation and beyond. *Man and Environment* 35.1: 62–75.

WEBER, S.A., A. KASHYAP & L. MOUNCE. 2011. Archaeobotany at Farmana: new insights into Harappan plant use strategies, in V. Shinde, T. Osada & M. Kumar (ed.) *Excavations at Farmana, District Rohtak, Haryana, India, 2006–8*: 808–25. Kyoto: Research Institute for Humanity and Nature.

WEBER, S.A. & A. KASHYAP. 2016. The vanishing millets of the Indus civilisation. *Archaeological and Anthropological Sciences* 8: 9–15.

WRIGHT, R.P. 2010. *The ancient Indus: urbanism, economy and society*. Cambridge: Cambridge University Press.

References (additional for SI)

ALLCHIN, B. & F.R. ALLCHIN. 1968. *The birth of Indian civilisation: India and Pakistan before 500 B.C.* Harmondsworth: Penguin.

– 1982. *The rise of civilization in India and Pakistan*. Cambridge: Cambridge University Press.

– 1997. *Origins of a civilization: the prehistory and early archaeology of South Asia*. Delhi: Viking.

BROCK, F., T. HIGHAM, P. DITCHFIELD & C. BRONK RAMSEY. 2010. Current pretreatment methods for AMS radiocarbon dating at the Oxford Radiocarbon Accelerator Unit (ORAU). *Radiocarbon* 52: 103–12.

CASTILLO, C.C., K. TANAKA, Y. SATO, R. ISHIKAWA, B. BELLINA, C. HIGHAM, N. CHANG, R. MOHANTY, M. KAJALE & D.Q. FULLER. 2015. Archaeogenetic study of prehistoric rice remains from Thailand and India: evidence of early japonica in South and Southeast Asia. *Archaeological and Anthropological Sciences*. doi:10.1007/s12520-015-0236-5

CHAKRABARTI, D.K. 1995. *The archaeology of ancient Indian cities*. Delhi: Oxford University Press.

– 2006. *The Oxford companion to Indian archaeology: the archaeological foundations of ancient India*. Delhi: Oxford University Press.

FAIRSERVIS, W.A. 1971. *The roots of ancient India: the archaeology of early Indian civilisation*. London: Allen and Unwin.

FUJIWARA, H. 1993. Research into the history of rice cultivation using plant opal analysis, in D.M. Pearsall & D.R. Piperno (ed.) *Current research in phytolith analysis: applications in archaeology and palaeoecology*: 147–58. Philadelphia: University of Pennsylvania Museum.

FUJIWARA, H., M.R. MUGHAL, A. SASAKI & T. MATANO. 1992. Rice and ragi at Harappa: preliminary results by plant opal analysis. *Pakistan Archaeology* 27: 129–42.

FULLER, D.Q. 2003. Indus and non-Indus agricultural traditions: local developments and crop adoptions on the Indian Peninsula, in S.A. Weber & W.R. Belcher (ed.) *Indus ethnobiology: new perspectives from the field*: 343–96. Lexington (KY): Lanham.

– 2005. Ceramics, seeds and culinary change in prehistoric India. *Antiquity* 79: 761–77.

FULLER, D.Q. & E.L. HARVEY. 2006. The archaeobotany of Indian pulses: identification, processing and evidence for cultivation. *Environmental Archaeology* 11: 219–46. doi:10.1179/174963106x123232

GDAL. 2010. *Geospatial Data Abstraction Library: Version 1.7.3*. Open Source Geospatial Foundation, http://gdal.osgeo.org

GHOSH, S.S. & K. LAL. 1963. Plant remains from Rangpur and other explorations in Gujarat. *Ancient India* 18–19: 161–75.

HARVEY, E.L. 2006. Early agricultural communities in northern and eastern India: an archaeobotanical investigation. Unpublished PhD dissertation, University College London.

KENOYER, J.M. 1998. *Ancient cities of the Indus Valley civilisation*. Karachi: Oxford University Press.

KINGWELL-BANHAM, E. & D.Q. FULLER. 2012. Shifting cultivators in South Asia: expansion, marginalisation and specialisation over the long term. *Quaternary International* 249: 84–95. doi:10.1016/j.quaint.2011.05.025

LUTHRA, J.C. 1936. Ancient wheat and its viability. *Current Science India* 4: 489–90.

MACKAY, E.J.H. 1931. Ivory, shell, faience, and other objects of technical interest, in J.H. Marshall (ed.) *Mohenjo-Daro and the Indus civilisation*: 586–87. London: Arthur Probsthain.

MADELLA, M. 2003. Investigating agriculture and environment in South Asia: present and future contributions of opal phytoliths, in S.A. Weber & W.R. Belcher (ed.) *Indus ethnobiology: new perspectives from the field*: 199–249. Lexington (KY): Lanham.

MARSHALL, J.H. (ed.). 1931. *Mohenjo-Daro and the Indus civilisation*. London: Arthur Probsthain.

MEADOW, R.H. 1989. Continuity and change in the agriculture of the greater Indus Valley: the palaeoethnobotanical and zooarchaeological evidence, in J.M. Kenoyer (ed.) *Old problems and new perspectives in the archaeology of South Asia*: 61–74. Madison: University of Wisconsin.

– 1998. Pre- and proto-historic agricultural and pastoral transformations in northwestern and South Asia. *The Review of Archaeology* 19: 12–21.

MILLER, H.-L. 2006. Water supply, labor requirements, and land ownership in Indus floodplain agricultural systems, in J. Marcus & C. Stanish (ed.) *Agricultural strategies*: 92–128. Los Angeles (CA): Cotsen Institute of Archaeology.

PETRIE, C.A. 2015. Mehrgarh, Pakistan, in G. Barker & C. Goucher (ed.) *Cambridge world history, vol. II*: 289–309. Cambridge: Cambridge University Press.

PIGGOTT, S. 1950. *Prehistoric India to 1000 B.C.* London: Penguin.

REDDY, S.N. 1994. Plant usage and subsistence modelling: an ethnoarchaeological approach to the Late Harappan of northwest India. Unpublished PhD dissertation, University of Wisconsin-Madison.

– 1997. If the threshing floor could speak: integration of agriculture and pastoralism during the Late Harappan in Gujarat, India. *Journal of Anthropological Archaeology* 16: 162–87.

– 2003, *Discerning palates of the past: an ethnoarchaeological study of crop cultivation and plant usage in India*. Ann Arbor (MI): International Monographs in Prehistory.

SANKALIA, H.D. 1962. *Indian archaeology today*. Bombay: Asia Publishing House.

THOMPSON, G.B. 1996. Ethnographic models for interpreting rice remains, in C. Higham & R. Thosarat (ed.) *The excavations at Khok Phanom Di, a prehistoric site in Central Thailand*: 119–50. London: Society of Antiquaries of London.

VISHNU-MITTRE. 1990. Plant remains, in J.P. Joshi (ed.) *Excavation at Surkotada and exploration in Kutch*: 388–92. New Delhi: Archaeological Survey of India.

VISHNU-MITTRE & R. SAVITHRI. 1975. Supposed remains of rice (*Oryza* sp.) in the terracotta cakes and pai at Kalibangan, Rajasthan. *The Palaeobotanist* 22: 124–26.

WEBER, S.A. 1989. *Plant and Harappan subsistence: an example of stability and change from Rojdi*. Unpublished PhD dissertation, University of Pennsylvania.

– 1992. South Asian archaeobotanical variability, in C. Jarrige (ed.) *South Asian archaeology 1989*: 283–90. Madison (WI): Prehistory Press.

WEBER, S.A. & D.Q. FULLER. 2008/09. Millets and their role in early agriculture. *Pragdhara* 18: 69–90.

WEISSKOPF, A., E. HARVEY, E. KINGWELL-BANHAM, M. KAJALE, R. MOHANTY & D.W. FULLER. 2013. Archaeobotanical implications of phytolith assemblages from cultivated rice systems, wild rice stands and macro-regional patterns. *Journal of Archaeological Science* 51: 43–53.

WHEELER, R.E.M. 1953. *The Indus civilisation*. Cambridge: Cambridge University Press.

WILLCOX, G.H. 1989. Étude archéobotanique, in H.P. Francfort (ed.) *Fouilles de Shortugaï recherces*: 175–85. Paris: Diffusion de Boccard.

– 1991. Carbonised plant remains from Shortughai, Afghanistan, in J.M. Renfrew (ed.) *New light on early farming: recent developments in palaeoethnobotany*: 139–53. Edinburgh: Edinburgh University Press.

– 1992. Some differences between crops of Near Eastern origin and those from the tropics, in C. Jarrige (ed.) *South Asian archaeology 1989*: 291–300. Madison (WI): Prehistory Press.