CHAPTER 11

ARCHAEOBOTANY AT FARMANA: NEW INSIGHTS INTO HARAPPAN PLANT USE STRATEGIES

BY STEVEN A. WEBER, ARUNIMA KASHYAP, AND LAURA MOUNCE

1 INTRODUCTION

By around 2600 BC, a highly organized, economically centralized and culturally integrated civilization had emerged in the northwestern part of South Asia. The Indus Civilization flourished in part due to its successful agricultural practices. To date, our knowledge of these agricultural practices is based primarily on an archaeobotanical record that relies almost entirely upon seed grains preserved through carbonization (Fuller and Madella 2002; Weber 2003). Further, fewer than 50 Harappan sites have been extensively or intensively sampled for archaeobotanical remains. The focus of this limited and biased study has been largely on cereal grains and pulses from Southwest Asia. Further skewing our understanding of Harappan plant use strategies is the fact that only few of the many ecologically distinct regions of this civilization have been adequately studied. To help fill in some of these gaps, an archaeobotanical project was initiated at the site of Farmana, located in the Ghaggar valley region of Haryana, India.

Our approach at Farmana was to incorporate multiple threads of evidence to get a clearer picture of the full range of plants being used at the site. The goal was to use the more traditional approach of carbonized seeds to identify general cropping patterns while using starch grains to identify direct evidence for human consumption and understand patterned relationships between plants and material culture.

Direct evidence of plant use, whether recovered from human remains or the surfaces of implements used for food processing, cooking, serving and storage, is significantly limited or missing from Harappan archaeobotany. As a result, certain questions have not been addressed, such as whether similar types of cereal grains, like wheat and barley were being used and processed differently, and whether certain food plants were associated with status or ritual. The lack of such direct evidence has also impeded our ability to identify patterned relationships between plants and material culture, for example, whether distinct foods were associated with specific ceramic vessels or tool types, and whether shifts in pottery style reflect shifts in plant taxa. The starch grain analysis at Farmana is allowing us to address these issues, as well as unambiguous demonstrate human consumption of specific plants.

The following paper will initially summarize independently our three distinct avenues of research, the ethnobotanical and experimental, macrobotanical and microbotanical. Although each of these approaches and subsequent data sets can stand on their own and will eventually be published independently, they supplement each other nicely and together form the basis of our interpretation of plant use at Farmana. As the analysis of some of the data is continuing, the results and discussion presented here may eventually need revising.

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2 STATUS OF HARAPPAN ARCHAEOBOTANICAL RESEARCH

Archaeobotany is best seen as a sub-specialty of archaeology concerned with reconstructing diets, inferring how plants were obtained and used, and describing changes in agricultural and dietary strategies over time (see: Hastorf and Popper 1988; Gremillion 1997; Pearsall 2000; Weber 1999, 2003; Fuller 2002). The archaeobotanical record of the Harappan civilization is for the most part based on macrobotanical data collected from fewer than 50 Harappan sites (Kajale 1991; Fuller 2002; Fuller and Madella 2002; Weber 2003). While at most of these sites the archaeobotanical material recovered was accidental finds representing less than 50 seeds (Weber 1991, 1992), there are a few examples where large, systematically collected and intensively sampled strategies were employed (Weber 2003). From these sites no more than 100 different species have been identified, of which few were found regularly in large concentrations within a single site. Fewer still occurred regularly from site to site, let alone throughout a given region (Fuller and Madella 2002). Cereals, especially "big cereals" such as wheat and barley have been most widely reported. The "small cereals" like millets and pulses are generally only recovered where flotation has been practiced (Weber 1992, 1998; Fuller and Madella 2002). Other types of crops, including fiber and oilseeds producing plants (cotton, linseed and sesame) and roots and tubers (ginger, turmeric and yams) have rarely been recovered at Harappan sites (Fuller and Madella 2002). Tropical fruits (natives such as mango, jamun and amala) and spices (such as black pepper, nutmeg, cinnamon, clove and asafetida), which might have been a part of the Harappan diet (Kenoyer 1998), are also minimally represented or missing from archaeobotanical record.

All agricultural models for the Indus civilization have been derived from this limited database. These include ideas about how agriculture and cropping strategies influenced Harappan culture and culture change (Kajale 1974 Costantini 1985; Saraswat 1986; Possehl 2003), and theories that there was a shift to multi-cropping during the Indus civilization (Jarrige 1985; Meadow 1989, 1996). Additionally, the proposition that the introduction of new species from other regions played a prominent role in changing the settlement system (Possehl 1986), or that the shift towards more localized cultural units and away from urban complexes was associated with, or even stimulated by, a "revolution" in agricultural resources and techniques (Jarrige 1985; Possehl 1986; Meadow 1996). The problem with these studies is that the sites they reference were excavated at different times using different methods, collection and analysis strategies, and were overly dependent on macrobotanical remains preserved through carbonization.

Over the last few decades, microbotanical analysis, such as starch grain and phytolith studies have become increasingly valuable in balancing the record. Archaeobotanists are using starch grain and phytolith analysis to identify early agriculture, distinguish between wild and domesticated species, differentiate the plant organs producing the microfossils, reconstruct the long distance movements and adoption of plants and past environments, and associate plants directly with human activity by recovering the microfossils from lithic tools, ceramics and even human and animal teeth (Atchinson and Fullagar 1998; Banks and Greenwood 1975; Boyadjian *et al.* 2007; Kashyap 2006; Cortella, and Pochettino 1994; Crowther 2005; Esau 1965; Fullagar *et al.* 1998; Loy 1994; Loy *et al.* 1992; Pearsall *et al.* 2004; Perry 2004; Perry *et al.* 2006; Piperno 2000, Torrence and Barton 2006; Reichert 1913; Zarillo and Kooyman 2006; 2008; Henry *et al.* 2007; Piperno and Dillehay 2008; Kashyap and Weber 2010a, b, c). However the systematic study of these plant microfossils for archaeological purposes is still limited in India. Few microfossil studies have been done (for example phytolith studies by Eksambekar *et al.* 1997; Eksambekar 1999; Madella 1995, 2003 and starch analysis by Kashyap 2006) and very little attempt has been made to compare the two forms of analysis.

Extensive models have been developed to explain the agricultural diversity and productivity of the civilization (see: Meadow 1996; Weber 1999, 2003; Fuller and Madella 2001). The common thread in these approaches is their focus on levels of precipitation by distinguishing regional moisture patterns and their impact on crop selection. As a result, two agricultural strategies are often proposed. One strategy, the rabi, involves crops sown in the autumn, harvested in the spring, and fed with winter rains. This strategy was most common at Harappan sites found in Baluchistan, Bannu Basin, Sindh, Punjab, Swat and Kashmir. Many of the winter crops, including wheat, barley, oats, peas, and lentils were introduced into South Asia from Southwest Asia. The second strategy, the kharif, centers on crops sown in the summer and harvested in the fall, making use of summer monsoon rains, and includes the cultivation of millets, rice, cotton, dates, and gram. Many of the summer crops were indigenous to the region or were introduced from somewhere else in South Asia. The agricultural strategy in Gujarat, Kutch, Rajasthan, and Maharashtra focused primarily on the kharif season. While both the rabi and kharif strategies were often practiced in the same area, the emphasis was generally on one season based on location. This pattern of dividing regions by agricultural strategies based primarily on cropping continues through the historic record into modern times. The archaeobotanical remains from Farmana imply that the region of the Ghaggar-Hakra of the Indus civilization was multicropped and incorporated both strategies during the Harappan Period, just as we see today.

3 ETHNOBOTANICAL AND EXPERIMENTAL STUDIES

ETHNOBOTANICAL

Ethnobotanical fieldwork was conducted in the modern village of Farmana and during January to March of excavation seasons 2008 and 2009. We collected information regarding the kinds of plants being consumed and the preparation of the plants for food consumption. We also collected information on hearth fuel, for both cooking and heating purposes. The informants were mostly females, but in households where men were in charge of buying food and gathering wood for the hearth men were also consulted. Over 15 households were interviewed using a semi-structured questionnaire. While most interviews lasted nearly three hours, in two cases we were invited to stay all day and observe the daily activities around the hearth. The interview questions focused on food plants, cooking practices, and fuel for the hearths. The goal was to better understand the archaeobotanical material being recovered from the Harappan occupation at Farmana. All interviews focused on seven general themes: (1) Who was in charge food preparation and fuel collection; (2) What kinds of foods are consumed and how they were prepared; (3) How much time is spent preparing, processing and cooking food; (4) How many hearths were in the household, what were their functions and where were they located; (5) What were the fuel options, when each type of fuel was used and how fuel was processed and stored; (6) How were hearths maintained. How often was the hearth cleaned and where was the debris deposited; (7) What was fed to the cows and how were dung cakes made, used and stored?

As expected, the data clearly demonstrates that women are mostly in charge of buying and preparing food for the household. Food preparation and cooking for the day are usually done in the morning. The every-day diet includes food crops/

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EXPERIMENTAL

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processing techniques affect starch
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cereals such as wheat (during summer), pearl millet (used along with wheat in the winter), occasionally rice and legumes (Vigna species and Bengal Gram). Vegetables are also consumed depending on what is available in the market and what is being grown in the vegetable backyard garden. Weeds such as 'bathua' (*Chenopodium album*) are also used widely for cooking. Chenopodium is a common weed found in disturbed soils and was present in many flotation samples. Its use as a food at Farmana village helps support the idea that its presence archaeologically may also have been as a food supplement.

A combination of fuel-wood, crop residues, and cattle dung was used for cooking and heating. Woman, children and young adults are usually responsible for collecting the wood. The most common wood types were 'shisam' (*Dalbergia sissoo*), 'kikar' (*Acacia karoo*) and 'kair' (*Acacia chundra*). The use of dung depended on hearth shape, function and what was being cooked. Most households had cattle, which were kept at times within the enclosed living compound. Cow dung was usually piled into an open space in the village with other vegetable material and household garbage. Some of the straw observed in these piles included attached seeds grains. These materials was then mixed into dung cakes and dried for fuel. All households had multiple hearths – at least one was specially used for cooking and another for heating purposes especially heating water used for drinking and for other household chores. Some households had over 13 hearths available for use at any given time. Most hearths were cleaned every 7-10 days.

EXPERIMENTAL

To better understand how cooking and processing techniques affect starch morphology (see microbotanical section of this paper) we have been conducting a series of experiments using clay pots and recipes gathered from our ethnographic research at the village of Farmana. Starches are organic and fragile nature. Thus food processing, preparation and cooking techniques can easily affect starch granules resulting in structural and morphological damage and gelatinization (breakdown of intermolecular bonds of starches) (Babot 2003; Campus-Baypoli 1999; Ratnayake and Jackson 2007; Takahashi and Shirai 1982). This is especially true when water and heat are involved. On the other hand alkali cooking techniques and use of salt and sugar can augment granular stability and increase the gelatinization temperatures, resulting in the survival of starches in the cooking-pot residues. Through experimentation, we are identifying the changes in the starch grain structure and morphology resulting from various cooking practices, and then attempting to identify these markers in the archaeobotanical record.

The cooking experiments have focused on vegetable curries, chutneys, roasting and boiling roots and tubers, making 'kheer' or pudding from rice, wheat pudding, making rotis (flat bread) from wheat flour, and brewing barley. All experiments were conducted in the archaeobotanical laboratory at Washington State University Vancouver (WSUV), with support from the National Science Foundation. The experiments are still continuing with additional support from WSUV. Our experiments with eggplant, ginger, turmeric and mango have all indicated that cooking does cause specific structural and morphological changes in starch granules. Further, the amount of time the plants were cooked, and the material in which the plants were cooked in, directly impact starch preservation (Kashyap and Weber 2010). Since many of these cooking markers (microscopic features) are also present in the macrobotanical samples, Harappan processing and cooking practices may be recognizable. Once the experiments are completed (late 2011) and all the ethnobotanical data is processed and analyzed, a comprehensive publication will be produced.

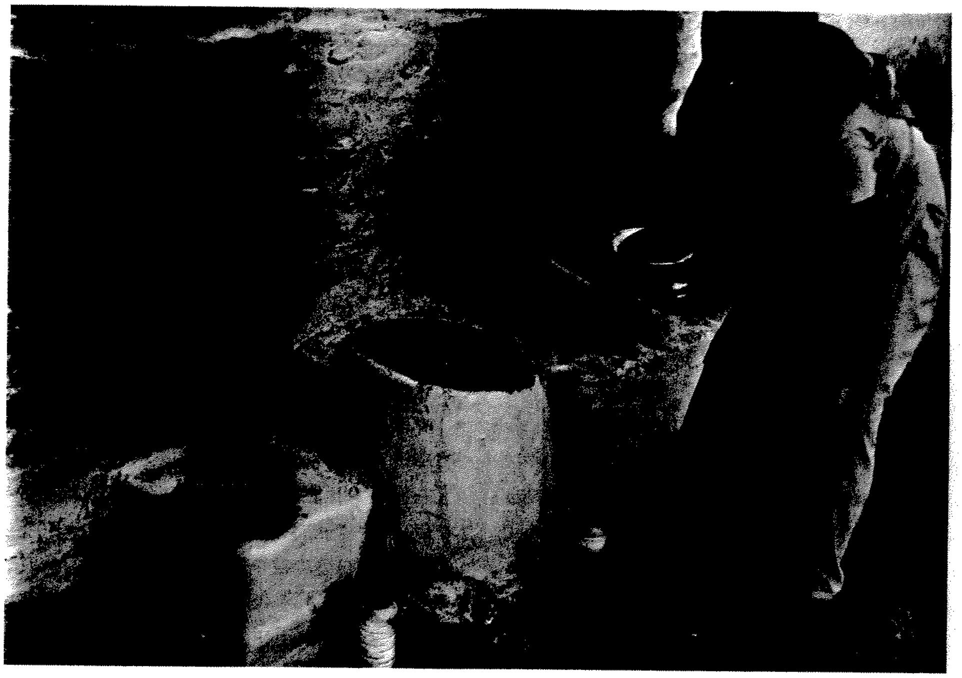

Figure 11.1 Collecting ethnographic data on plant processing, cooking and hearth use

Figure 11.2 Flotation at Farmana

4 MACRO-BOTANICAL

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4 MACRO-BOTANICAL ANALYSIS

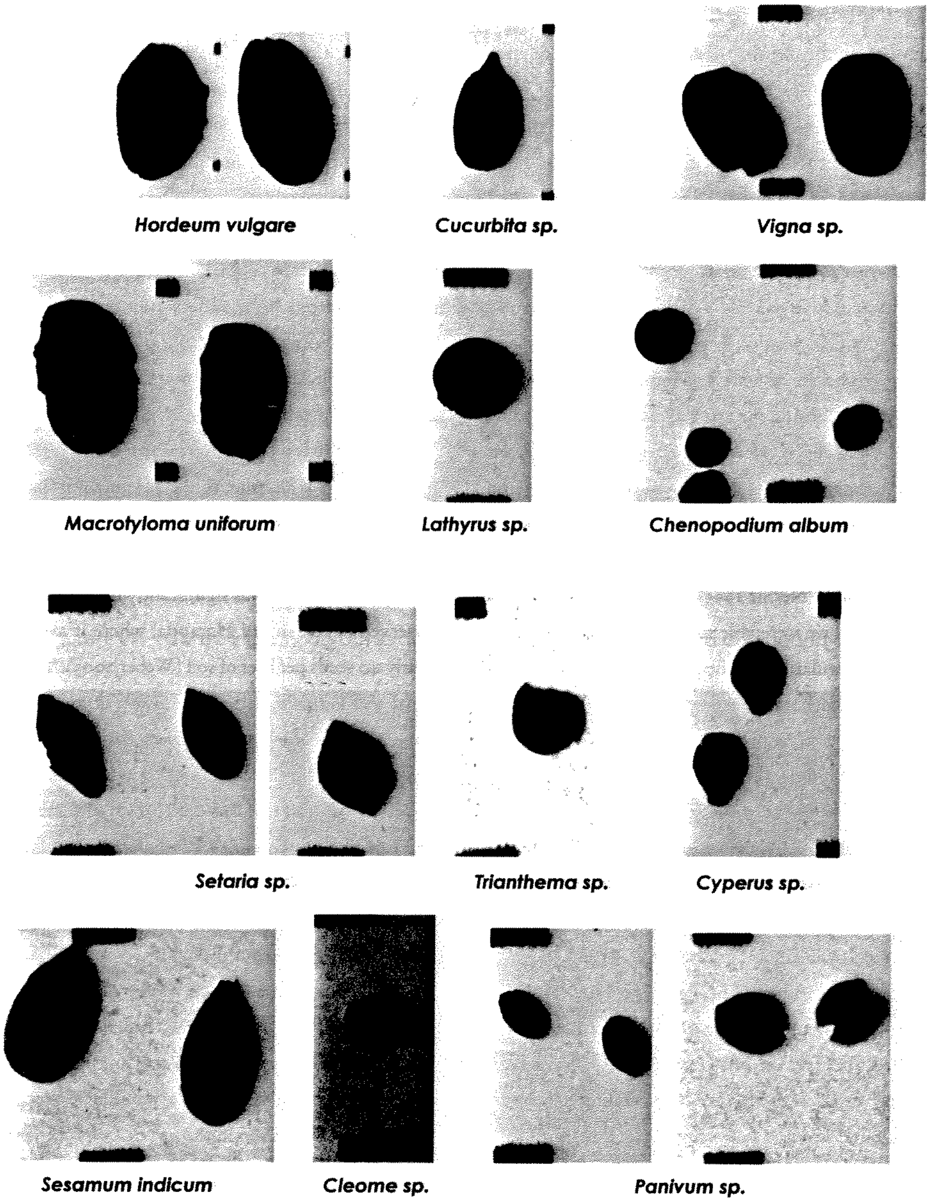
While macro-botanical remains typically account for the majority of the archaeobotanical data collected from an excavation, this was not the case at Farmana where a more balanced approach was applied. Carbonized seeds, chaff and charcoal -- the bulk of the macro-botanical materials -- represented only one avenue of research and thus only a portion of the Farmana plant material.

Over a two-year period, during both the 2008 and 2009 field seasons, 143 soil samples were floated for macro-botanical material. A flotation machine was constructed during the 2008 excavation season using an old 50 gallons oil drum. Our design was based on a standard Siraf type machine that used a .5 mm mesh to recover the heavy residue and .1 mm cloth sieve for the lighter plant materials (Williams 1973; Watson 1976; Nesbit 1995). By using a pump and a nearby well we were able to process large volumes of soil on a regular basis. The goal was to systematically collect 20 liters samples from all floor, features and stratigraphic layers. In some smaller contexts, such as features including pits and hearths, however, samples of only several liters were collected. The result was a quantifiable and comparative database.

One hundred and forty soil samples were collected and floated. Five of these samples were collected from the cemetery, the rest from the main settlement mound. The heavy residue from the samples was collected, dried, and sorted at the site during the excavation. Charred bone fragments, beads, small terracotta cakes were common, but very little botanical remains were found. The finds were identified, weighed, and distributed to the various specialists. The light fraction samples were dried and shipped to the archaeobotany lab at Washington State University Vancouver (WSUV). Under a low powered dissecting microscope the seeds, chaff and charcoal were removed for analysis.

The sampling strategy was devised to examine temporal changes in crop use strategies over the occupation of the site. Yet it became evident during the excavation that the site was quite shallow, occupied only during the Mature Harappan Period and was heavily disturbed. Based on the stratrigraphy, ceramics and the carbon (AMS) dates, the site was occupied between 2600 and 2200 BCE. While a number of distinct Harappan phases could be identified, the site was occupied for a relatively short period. As a result we saw little reason to analyze all collected samples. Our goal shifted from understanding change over time to describing cropping and plant use strategies at one point in time. At this point in time, 67 of the flotation samples have been analyzed.

The results from flotation suggest that preservation was an issue. While ubiquity was high, at nearly 97 percent, seed density was relatively low. The average seed density for Farmana was less than 5 seeds per liter of soil. This was significantly below what was observed at the site of Harappa, where it averaged nearly 40 seeds per liter of soil (Weber 2003). The low density at Farmana might be a result of less intense fire exposure leading to fewer seeds being carbonized or a result of the site being smaller with a less dense population. The shallow nature of the cultural deposits and constant impact from later activities may also be an issue. Less than twenty different taxa were represented in the seed record (See Table 11.1). Of these, only 9 were definitively food crops. Like other Harappan sites, cereals made up the majority of the carbonized seeds. The primary cereals were wheat (*Triticum sp.*), barley (*Hordeum sp.*) and several small millets (*Panicum sp.* and *Setaria sp.*). One fragmented rice grain was observed in the upper levels of the site. Its context and the lack of additional grains suggest that rice did not play an important role at Farmana. Seeds from a variety of pulses and fruits were also identified (Table 11.1). Green gram (*Vigna sp.*), horse gram (*Macrotyloma sp.*) and sesame (*Sesamum sp.*) were the most frequently recovered crop seeds after the cereals. It is clear that the cropping pattern for


Hordeum vulgare **Cucurbita sp.** **Vigna sp.**

Macrotyloma uniforum **Lathyrus sp.** **Chenopodium album**

Setaria sp. **Trianthema sp.** **Cyperus sp.**

Sesamum indicum **Cleome sp.** **Panivum sp.**

Figure 11.3 Examples of some of the more commonly recovered seeds from Farmana For scale, the marks in each picture correspond to 1mm

Figu

Farmana was one based on both sur watered crops.

The few flotation samples collec from the cemetery area contained result we focused our attention o area. Two trenches from the settl and 1C11, represented the least dist and contained the best-preserved material. Efforts to identify shifts i primarily based on material from Because of the narrow time fram 400 years of occupation, and the of many of the sequences, we com levels of occupation (Phases 1 and levels (Phases 4 and 5) to get some s shifts occurring at Farmana. Using t then compared the ubiquity and se winter and summer cereals (Table 1 of samples with wheat and barley from 61 percent to 20 percent while

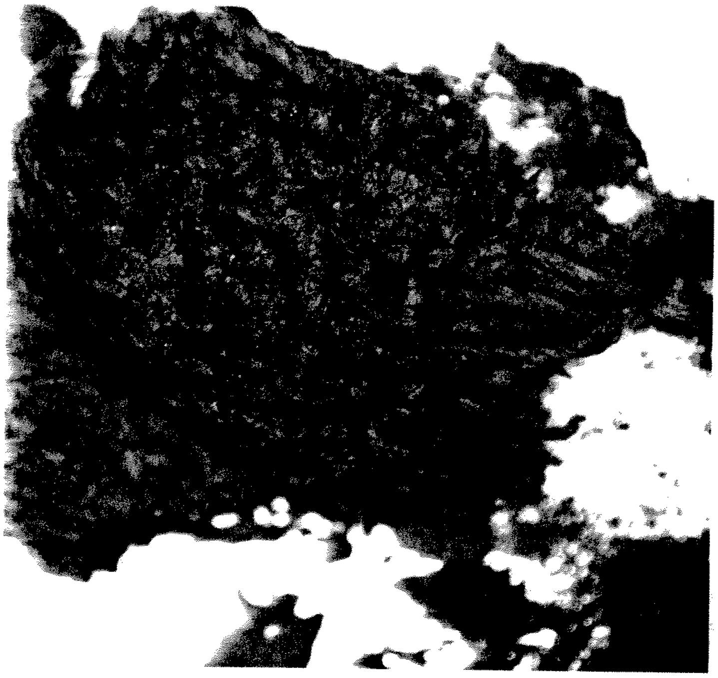


Figure 11.4 Cloth fragment from Farmana

Farmana was one based on both summer and winter watered crops.

The few flotation samples collected and analyzed from the cemetery area contained few seeds. As a result we focused our attention on the settlement area. Two trenches from the settlement area, 1D5 and 1C11, represented the least disturbed sequences and contained the best-preserved macro-botanical material. Efforts to identify shifts in cropping were primarily based on material from these trenches. Because of the narrow time framework, less than 400 years of occupation, and the disturbed nature of many of the sequences, we compared the earliest levels of occupation (Phases 1 and 2), with the later levels (Phases 4 and 5) to get some sense of cropping shifts occurring at Farmana. Using this framework we then compared the ubiquity and seed density of the winter and summer cereals (Table 11.2). The ubiquity of samples with wheat and barley grains declined from 61 percent to 20 percent while their seed density declined from an average of 1.5 to 0.7 seeds per liter of soil. Together, the implication is a dramatic decline in winter cereals. In contrast, the summer cereals had only a minor decline in ubiquity and a slight increase in seed density. Over all, the implication is that there was not only a decline in seed crops but a shift in seasonal emphasis from a winter based strategy to one more equally dependent on both seasons.

Charcoal and chaff were also collected from the flotation samples. Charcoal, a good indicator of climate, is still being identified. Preliminary analysis has led to the identification of two species, *Tamerix sp.* and *Salvadora sp.* Both are typical of a thorn forest with semi-arid trees and shrubs. Chaff made up a very small portion of the macro-botanical material either due to issues of crop processing or preservation. A single carbonized fragment of what appears to be a garlic clove (*Allium sp.*) was also recovered.

One of the most interesting finds at Farmana was a very small fragment (1 mm) of woven plant material

Table 11.1 Plant taxa identified at Farmana. Species identification was not always possible. In such circumstances, the remains were categorized by family.

	Macro-botanical	Micro-botanical
CEREALS		
Hordeum vulgare (hulled barley)	S	
Hordeum sp. (barley)	S	T
Triticum aestivum (bread wheat)	S	
Triticum sphearococcum (dwarf wheat)	S	
Triticum sp. (wheat)	S	
Panicun sumatrense	S	
Panicun sp.	S	T, L
Brachium rumosa	S	
Setaria sp.		T
Sorghum sp.		L-?
Oryza sativa	S-?	
PULSES or VEGETABLES		
Vigna sp. (gram)	S	T
Vigna radiate (green gram)	S	
Solanum sp. (eggplant)		L, P
Macrotyloma sp. (horse gram)	S	T, P
Lens culinaris (lentil)	S	
Latherus sp.	S	
FRUITS, OIL SEED or FIBER		
Cucurbita sp.	S	L-?
Mangifera sp. (mango)		L
Sesamum indicum (sesame)	S	
Linum sp. (linseed)	S	
Unknown	F-?	
SPICES, HERBS		
Allium sp. (garlic clove)	V-?	
Zingiber sp. (ginger)		P
Curcuma sp. (turmeric)		P
OTHER		
Cyperus sp.	S	L
Dioscorea sp.		L
Rumex dentatus	S	
Aegilops sp.	S	
Abutilon sp.	S	
Cleome sp.	S	
Chenopodium album	S	
Chenopodium sp.	S	
Trianthema portulacastrum	S	
Trianthema triquetra	S	
Tamerix sp.	C	
Salvadora sp.	C	
Unknown	S	

S=Seed C=Charcoal Clove=V Fabric=F ?=Possible But Fragmented
T=Starch on Teeth L=Starch on Stone P=Starch on Pottery

Tabl

Winter Cereals

Summer Cereals

(Figure 11.4). The cloth fragment wa
the lower levels of Trench 1D5 and a
around 2500 BCE. While the cloth
being analyzed, it appears to be mad
hemp.

5 MICRO-BOTANICAL

Two types of micro-botanical d
at Farmana, starch grains (con
carbohydrates) and phytoliths (op
Although starch grains and phyt
studied for nearly two centuries, the
of these plant microfossils for archae
dates only to the last few decades (Es
1913; Schleidon 1849). Increasingly,
are using phytoliths and/or starch
additional plant species that are
preserved in the carbonized seed re
and Fullagar 1998; Barton *et al.* 19
1998; Hall *et al.* 1989; Kashyap 200
et al. 1992; Pearsall 2004; Piperno *e*
Our emphasis at Farmana has been
were successfully recovered from a
and were well preserved. Our star
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STARCH GRAINS

Starch grains are complex insolu
that serve as the plant's princi
mechanism. They have distinctive fe
and structure) that are geneticall

Table 11.2 Seed rates for Farmana cereals

		Seed Density	Ubiquity
Winter Cereals			
	Early Levels	1.5	61
	Late Levels	0.7	20
Summer Cereals			
	Early Levels	0.6	38
	Late Levels	0.7	30

(Figure 11.4). The cloth fragment was recovered from the lower levels of Trench 1D5 and appears to date to around 2500 BCE. While the cloth fragment is still being analyzed, it appears to be made of either jute or hemp.

5 MICRO-BOTANICAL ANALYSIS

Two types of micro-botanical data were available at Farmana, starch grains (complex insoluble carbohydrates) and phytoliths (opal silica bodies). Although starch grains and phytoliths have been studied for nearly two centuries, the systematic study of these plant microfossils for archaeological purposes dates only to the last few decades (Esau 1965; Reichert 1913; Schleidon 1849). Increasingly, archaeobotanists are using phytoliths and/or starch grains to identify additional plant species that are not necessarily preserved in the carbonized seed record (Atchinson and Fullagar 1998; Barton *et al.* 1998; Fullagar *et al.* 1998; Hall *et al.* 1989; Kashyap 2006; Loy 1994; Loy *et al.* 1992; Pearsall 2004; Piperno *et al.* 2000, 2004). Our emphasis at Farmana has been on starches, which were successfully recovered from a variety of surfaces and were well preserved. Our starch analysis is still continuing but should be completed in late 2011.

STARCH GRAINS

Starch grains are complex insoluble carbohydrates that serve as the plant's principal food storage mechanism. They have distinctive features (size, shape and structure) that are genetically controlled and, when carefully studied, can be used to identify plant taxa (Banks and Greenwood 1975:242; Cortella and Poschettino 1994: 172; Hardy *et al.* 2008; Loy 1994: 87-91; Reichert 1913: 165; Zarrillo and Kooyman 2006: 484).

In the last two decades starch grain extracted from various archaeological contexts has become a very useful and widely applicable technique around the world for studying direct evidence of plant use and consumption. Starch-grain analysis has been used to study plant diet and use, plant domestication, cultivation and processing, food preparation, ceramic residue analysis, tool use and site organization in various parts of the world (Atchinson and Fullagar 1998; Babot and Apella 2003; Barton *et al.* 1998; Fullagar *et al.* 1998; Henry and Piperno 2007; Kashyap 2006; Loy *et al.* 1992; Perry 2004, 2005; Perry *et al.* 2006; Piperno and Holst 1998; Piperno *et al.* 2000; Zarrillo and Kooyman 2006; Zarillo *et al.* 2008). Starch grains are also increasingly being used as markers of diet (Boynadjian *et al.* 2007; Hardy *et al.* 2008; Henry and Piperno 2007; Piperno and Dillehay 2008). Our starch study at Farmana was the first for a Harappan site. Our goals were to demonstrate that starch grains could be successfully recovered from artifact surfaces, to identify plant-processing activities, and to directly identify dietary practices.

At Farmana we collected samples from 240 surfaces that could be studied for both starch grains and phytoliths. The samples were collected from both the living and cemetery regions of the site. All samples were collected during the 2009 excavation season. These included 54 burial vessels (of various shapes and

Table 11.3 Sample sources for starch analysis

Type of Sample	***Occupational Phase***	***Archeological Context***	***Samples Studied***
Human Teeth	Mature Harappan	Cemetery Burials	9
Pottery Storage or Cooking Pots	Mature Harappan	Habitation Area Floor Trash Hearths Storage areas Structures	20 8 storage pots 8 cooking pots 4 Sherds
Stone Artifacts blades grinders pounders	Mature Harappan	Habitation Area Floor Trash Hearth Storage areas	10 2 lithic blades 4 grinding stone 4 pounders
Sediment Sample or Control Sample	Mature Harappan	Around sampled artifacts	11

sizes and types), 100 ceramic vessels (of various shapes and sizes and types), 30 grinding tools, 16 stone blades, and 40 human teeth/dental calculus.

So far we have studied 50 samples (including human tooth calculus, pottery and atone artifacts) from Farmana (Table 11.1). We sampled nine teeth (1 premolar, 1 molar and 1 incisor) from three human burials belonging to the Mature Harappan Phase at Farmana. In total 20 ceramic vessels or pottery sherds were studied for the pilot project. The analyzed ceramics came from a variety of contexts including mud brick structures, living floors, trash areas and hearths. Studies have shown that food residues most often occur as consolidated and blackened material accumulated on the walls and the base of the ceramic vessels. They also appear in the form of whitish crusts on the exterior of the vessels or charred residues on the work surface of the pottery fragments. The cooking and storage pots were examined very carefully for such residues. Stone implements including two lithic blade tools, four grinding stones, four pounders and the soil sediments adhering to some of these tools were also studied for the pilot project. The stone implements were collected from various contexts (house floors, area around the hearth and other features) at the site. We also studied control samples collected from directly beneath and around the periphery (to a distance of 5-10 cm) of the ceramic and stone implements to assess if non-use contamination may be an issue (Kashyap 2006; Perry 2004; Piperno 2006; Zarillo *et al.* 2008).

For the recovery of the starches from dental calculus we followed the strategy outlined by Piperno and Dillehay (2008: 19626). The sampled teeth were brushed with a soft toothbrush and water to remove adherent soil and other particles. A dental pick was used to scrape different areas of teeth (crown of molars, gum lines etc.) with visible calculus. The extracted residue was directly transferred to a microscopic slide with a few drops of water on it. Before putting on the cover slip, one drop of 50% water/glycerin was added to the residue water suspension to slow the drying of the grains and allows the grains to be easily rotated when encountered

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(Piperno and Dillehay 2008). **Residu**
and processed for starch granules fro
vessels by a multiple-step metho
successive washes to loosen residue,
to concentrate the residue, and t
them to microscopic slide for obse
2006). Charred residues were re
help of a dental pick from the interi
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were obtained and processed for
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involved a fine point needle to loo
cracks and crevices, using a centrifu
the residue, and then transferring the
slide for observation (Piperno 200
were extracted from pounders by
an ultrasonic bath to completely d
sediment and starch. We then isolat
adding a heavy liquid solution.

Starch grains from the soi
extracted by using the following m
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cover was examined. When a sta
located, it was studied under 400×.
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and notes were taken describing th
starches for identification purposes.
was also photographed. When the
complete colorless nail was used to

(Piperno and Dillehay 2008). Residues were extracted and processed for starch granules from storage pottery vessels by a multiple-step method that involved successive washes to loosen residue, using a centrifuge to concentrate the residue, and then transferring them to microscopic slide for observation (Piperno 2006). Charred residues were removed with the help of a dental pick from the interior surfaces of the sherds by gently scraping with a sterilized dental pick, pretreated with mild oxidation, and the starch isolated by a heavy-density liquid separation. Residues were obtained and processed for starch granules from ground stones by a multiple step method that involved a fine point needle to loosen residue from cracks and crevices, using a centrifuge to concentrate the residue, and then transferring them to microscopic slide for observation (Piperno 2004). Starch grains were extracted from pounders by shaking them in an ultrasonic bath to completely dislodge adhering sediment and starch. We then isolated the starches by adding a heavy liquid solution.

Starch grains from the soil samples were extracted by using the following method. 2 g of dry sediment was mixed well with Calcium Carbonate and left overnight to settle. This mixture was centrifuged and liquid was poured off carefully. To the mixture a heavy liquid solution was added and it was centrifuged. The supernatant was extracted and centrifuged with reverse osmosis water to get rid of any chemicals. The residue was removed and mounted on to a microscopic slide. The extracts were thoroughly studied with research grade transmitted light microscopy under polarizing lights. Slides were scanned at 200× until the entire area under the glass cover was examined. When a starch granule was located, it was studied under 400×. Each starch grain was rotated using pressure to view all dimensions and notes were taken describing the attributes of the starches for identification purposes. Each starch grain was also photographed. When the examination was complete colorless nail was used to seal the slide and curate for future analysis (Kashyap 2006, Perry 2004).

The identification of the starch granules to plant taxa involved the use of photographs and descriptions as well as comparative starch specimens from modern plants (Kashyap 2006; Perry 2004:1075). The initial step was the identification of the study of the basic morphology of the starch granule. The next step was to note the more detailed characteristics of the granule such as:

1) overall grain type (simple or compound) and shape (bell-shaped, circular, lenticular or oval)
2)contour and surface features,
3)position and form of the hilum (the botanical centre of the grain) and fissure (internal cracks emanating from the hila of some starch grains, formed when the grain begins to grow outward from the hilum and quite literally cracks),
4) number and characteristics of pressure facets present on compound grains,
5) the birefringent or Maltese cross pattern which is clearly visible under polarized light, and,
6)the presence or absence of demonstrable lamellae (rings formed during starch grain growth) (Piperno *et al.* 2004: 672).

Identification was based on a modern reference collection of over 200 different species from 40 families that Dr. Kashyap has put together. In addition, we made use of other databases and plant keys collected and published from other regions of the world (see: Cortello and Pochettino 1994; Henry and Piperno 2007; Piperno *et al.* 2004; Reichert's 1913; Seidemann 1966).

The starch grain research at Farmana is providing the first direct evidence for plants being used, processed and consumed at the site. We have successfully identified starches belonging to barley, small and large millets, and mango from a variety of grinders and pounding stones. Starches of lentils and large and small-grained cereals were recovered from the interior surface of storage jars, as for example the starch from *Macrotyloma sp., Solanum* (cf. eggplant), *zingiber* (cf. ginger) and *curcuma* (cf. turmeric) from a cooking pot or *handi* (a deep narrow-mouthed cooking vessel) (Kashyap and Weber 2010). Our success in extracting and identifying starches in human calculus from burials represents an innovation in South Asian archaeology. The study from 10 different individuals shows that the Harappans had a broad diet which included small grained-cereals, pulses, fruits, vegetables and roots and tubers, with wheat and barley apparently underrepresented in the starches (Kashyap and Weber 2010a) (Table 11.2).

6 SIGNIFICANCE OF FARMANA PLANT DATA

The diet at Farmana appears to have included a variety of crops likely grown locally. Like most Harappan sites, the focus was on cereals and pulses. What is clear is that a combination of indigenous millets and Southwest Asian cereals led to a secure multi-cropping strategy that was in place from the beginning of the occupation of Farmana. This strategy incorporated both summer and winter crops. Rice does not appear to be part of that strategy. With the addition of starch analysis we have an even clearer picture of cropping and diet as a number of species were identified that were not present in the seed record (Table 11.1). Millets, barley and gram were crops that were absolutely being consumed at Farmana as they were found in human dental calculus. Ginger, turmeric, mango, eggplant and possibly sorghum were all identified in the starch record but not found in the seed record. These results clearly demonstrate the need for incorporating different approaches. Independently, the seed grain or a starch grain approach would have missed some species for different reasons. Our study implies that many spices, herbs, fruits and root crops may have played a more important role in Harappan agriculture that previously realized.

Further, specific species correlate well with specific types of artifacts. Eggplant and mango were more often found on long narrow stone blades. Some blades were covered with just eggplant starches and nothing else. In contrast, spices and herbs were only found on the surfaces of ceramics. Different shaped vessels with different design elements seem to be associated with specific plants. At Farmana, we are only just beginning to understand the link between plant use and the material record. Much more work needs to be done along these lines before we truly understand this relationship

Over the short occupation of the site, a cropping shift appears to have occurred. Wheat and barley decline in use by nearly 60 percent while millet use remains constant. The net result is an increasing emphasis on the summer crops. This observed shift in the carbonized seed record may be a result of a number of different natural and cultural processes. The disturbed nature of the site and a flawed sampling strategy could skew our results. Yet the sample was large and diverse enough that any bias should have been accounted for. A change in crop processing methods or locations might also alter the recovery of seed crop. Yet the lack of any significant shift in weed seeds, chaff or seed density would suggest that plant processing was not the cause. A change in climate or specifically a decline in winter rains might be a factor. If a shift in moisture patterns were the sole cause and if the population remained stable, then there should have been an increased presence in summer crops. A slight decline in population associated with a decline in winter rains would account for the shifting seed pattern.

Archaeobotany at Farmana is also contributing to our understanding of Harappan plant economy in the Haryana region. Other sites in the region, like Balu, were successfully sampled and archaeobotanical remains were recovered (Saraswat and Pokharia

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7 CONCLUS

Analysis of the Farmana da
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approaches. Seeds, charcoal, sta
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2002). While the data from these sites are not quantifiable, they do contain many of the same crops. The biggest difference appears to be a greater dependence on wheat, barley and rice than what we found for Farmana. This discrepancy could be the result of sampling, methods of floating or actual difference in crop choice. Because of the limited data set, no real overreaching plant use model has yet been developed for the Haryana region of the Indus civilization.

To adequately understand Harappan cropping and their agricultural strategy, each individual region of the Indus civilization needs to be studied independently. One unique characteristic of the civilization was that it incorporated great diversity in ecology and culture. Soils, climates and moisture patterns differentiate one region from another and subsequently crops varied. As moisture patterns shifted and climates changed, each region adapted differently. In the Haryana region, and at Farmana in particular, people had access to a great variety of both summer and winter crops. As a result, people living in the region might have been better able to adapt to climatic shifts.

7 CONCLUSION

Analysis of the Farmana data is still continuing and will for some time. Nonetheless, enough archaeobotanical data has been analyzed that some important conclusions can be made. First and foremost, the project clearly demonstrates the need to incorporate different archaeobotanical approaches. Seeds, charcoal, starches, and phytoliths represent different parts of a plant, since they preserve differently in the archaeological record, they can help us identify the different kinds of activities during the Indus Valley civilization. Together, a much clearer and broader picture emerges, one in which many of the internal biases of any single approach is nullified. Starch remains from ginger, turmeric and eggplant represent species that would not normally be preserved in the seed record. Ultimately, Farmana starches will allow us to better link plant use to the material culture.

With large volumes of systematically collected and floated soil we were able to identify wheat, barley and millets as the primary cereal crops for Farmana. Over the occupation of the site, the winter cereals declined in importance. Millets remained important and rice never played an important role. This shift may have been a result of changes in the moisture pattern. Specifically, Farmana might have experienced a decline in the winter rains during the later phases.

The distinctiveness of the Farmana data clearly demonstrates that understanding regional and temporal variability is an important key to modeling Harappan agricultural practices. Our tendency to focus on general moisture patterns that impact large regions of South Asia often fails to recognize how local environments and different regional ecosystems determine diverse and distinct agricultural communities. There were many distinct agro-zones during the Indus civilization (Weber *et al.* 2010). Each developed their own unique agricultural strategy and responded differently to changes in climate. With the addition of each individual Harappan site, like Farmana, regional patterns become clearer. It is only after we understand these regional patterns that we can clearly explain the evolution of Harappan agriculture.

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References

Atchinson, J and R. Fullagar (1998) Starch Residue on Pounding Implements from Jinmium Rock Shelter. in R. Fullagar (ed.) *A Closer Look: Recent Australian Studies of Stone Tools*, edited by , pp. 109-126. SUAMS 6, Archaeological Computing Laboratory, Sydney.

Babot, M. del Pilar (2003) Starch Grain Damage as an Indicator of Food Processing. In D. Hart and L. Wallis (eds.) *Phytoliths and Starch Grain Research in Australian -Pacific-Asian Regions: The State of Art.* Tera Australis; 19, Pandanus Books, Research School of Pacific and Asian Studies, the Australian National University, Canberra. pp.69-81.

Babot, M. del Pilar and M. C. Appella (2003) Maize and Bone: Residue of Grinding in Northwestern Argentina. *Archaeometry* 45: 121-132.

Banks, W. and C. T. Greenwood (1975) *Starch and its Components.* Edinburg University Press, Edinburg.

Barton, H., R. Torrence and R. Fullagar (1998) *Clues to Stone Tool Function Re-examined: Comparing Starch Grain Frequencies.* ++++

Boyadjian, C.H.C., S. Eggers, K. Reinhard (2007) Dental wash: a problematic method for extracting microfossils from teeth. *Journal of Archaeological Science* 34:1622-1628.

Campus-Baypoli ON, Rosas-Burgos EC, Torres-Cha'vez PI, Ramı'rez-Wong B, Serna-Saldı'var S. O. (1999) Physiochemical changes of starch during maize tortilla production. *Starch* 51:173–177.

Constantini, L. (1985) Agriculture in Baluchistan between 7th and 3rd millennium B.C. *Newsletter of Baluchistan Studies* 2: 16-30.

Cortella, A.R. and M.L. Pochettino (1994) Starch Grain Analysis as a Microscopic Diagnostic Feature in the Identification of Plant Material. *Economic Botany* 48: 171-181.

Crowther, A. (2005) Starch Residue on undecorated Lapita Pottery from Anir, New Ireland. *Archaeology of Oceania* 40: 62-66.

Esau, K. (1965) *Plant Anatomy.* Wiley, New York.

Fullagar, R., T. Loy, and S. Cox (1998) Starch Grain Sediments and Stone Tool Function: Archaeological Evidence for Plant Foods In R. Fullagar (ed.) *A Closer Look: Australian Studies of Stone Tools.*SUAMS 6. Archaeological Computing Laboratory, Sydney. pp.49-60.

Fuller, D. Q. 2002. Fifty years of Archaeobotanical studies in India: Laying a solid foundation. In R. Korisettar and S. Settar (eds.) *Indian Archaeology in Retrospect: Proto history Archeology of the Harappan Civilization.* ICHR/ Manohar, New Delhi. pp.247-264.

Fuller, D. Q and M. Madella (2002) Issues in Harappan Archaeobotany: Retrospect and Prospect. In R. Korisettar and S. Settar (eds.) *Indian Archaeology in Retrospect: Proto history Archeology of the Harappan Civilization.* ICHR/Manohar, New Delhi. pp.317-390.

Gremillion, K.J. (1997) *People, Plants and Landscape: Studies in Paleoethnobotany.* University of Alabama press, Tuscaloosa.

Hardy, K. (2008b) Prehistoric string theory. How twisted fibers helped to shape the world. *Antiquity* 82: 271–280.

Hastorf, C.A. and V.S. Popper (1988) *Current Paleoethnobotany: Analytical Methods and Cultural Interpretations of Archaeological Plant Remains.* University of Chicago Press, Chicago.

Henry, A. and D. Piperno (2007) Using plant microfossils from dental calculus to recover human diet: a case study from Tell al- Raq!a'i, Syria. *Journal of Archaeological Science* 35: 1943-1950.

Henry, A., H. F. Hudson and D. Piperno (2009) Changes

in Starch Grain Morphology from C
Archaeological Science. ++++.

Jarrige, J.-F. (1985) Continuity and Cha
Kachi Plain at the beginning of se
B.C. In J. Schotsmans and M. Taddei
Archaeology 1983. IsMEO, Naples. pp.

Kashyap, A. (2006) *Use-wear and Starch
Integrated Approach to Understandin
Food Production at Bagor, Rajasthan,*
Dissertation, MSU.

Kashyap, A and Steve Weber (2010a) S
Farmana Give New Insights into H
(Antiquity Project Gallery, Novembe

Kashyap, Arunima and Steve Weber (
analysis of Starches from Cattle
Implications for Indus Ethnobotany
press *The Harappa Archaeological R
2007: Documentation, Analyses, an*
BAR publication).

Kashyap, Arunima and Steve Weber (20
Harappan Cooking Practice
Experimental Residue Study, (in p
Complexity. Left Coast Press).

Kajale, M. (1974) Ancient grains fro
Deccan College Research Institute, 34

Kajale, M. (1991) Current Status of India
Introduced and Indigenous food Pla
of the Historical and Evolutiona
Indian Agriculture and Agricultura
In J. Renfrew (ed.) *New Lights on E
Developments Paleoethnobotany*. E
Press, Edinburgh. pp.155-189.

Eksambekar, S.P., S.R. Sainkar and M. K
Studies Using Scanning Electron
Some Initial Considerations. *Bull
Post-Graduate and Research Institu*

Eksambekar, S.P. (2001) Phytolith T
Notes on Silex. The Phytolitharien
for Phytolith Research 13 (2and3): 1

Kenoyer, J. M. (1998) *Ancient Cities
Civilization*. American Institute
Oxford.

Kenoyer, J. M. (2008) Indus Civilizati
Encyclopedia of Archaeology. Acad
and Oxford, UK. pp.715-733.

in Starch Grain Morphology from Cooking. *Journal of Archaeological Science*. ++++.

Jarrige, J.-F. (1985) Continuity and Change in the North Kachi Plain at the beginning of second millennium B.C. In J. Schotsmans and M. Taddei (eds.) *South Asian Archaeology 1983*. IsMEO, Naples. pp.35-68.

Kashyap, A. (2006) *Use-wear and Starch Grain Analysis: an Integrated Approach to Understanding the Transition to Food Production at Bagor, Rajasthan, India*. Unpublished Dissertation, MSU.

Kashyap, A and Steve Weber (2010a) Starch Grains from Farmana Give New Insights into Harappan Plant Use (Antiquity Project Gallery, November 2010).

Kashyap, Arunima and Steve Weber (2010b) Preliminary analysis of Starches from Cattle Tooth at Farmana: Implications for Indus Ethnobotany (R. Wright (ed.) in press *The Harappa Archaeological Research Project 2001-2007: Documentation, Analyses, and New Excavations*. BAR publication).

Kashyap, Arunima and Steve Weber (2010c) Understanding Harappan Cooking Practices: A Preliminary Experimental Residue Study, (in press *Connections and Complexity*. Left Coast Press).

Kajale, M. (1974) Ancient grains from India, *Bulletin of Deccan College Research Institute*, 34: 55-74.

Kajale, M. (1991) Current Status of Indian Paleoethnobotany: Introduced and Indigenous food Plants with a Discussion of the Historical and Evolutionary Developments of Indian Agriculture and Agricultural Systems in General. In J. Renfrew (ed.) *New Lights on Early Farming – Recent Developments Paleoethnobotany*. Edinburgh University Press, Edinburgh. pp.155-189.

Eksambekar, S.P., S.R. Sainkar and M. Kajale (1999) Phytolith Studies Using Scanning Electron Microscope (SEM): Some Initial Considerations. *Bulletin of Deccan College Post-Graduate and Research Institute* Vol. 58-59: 85-92

Eksambekar, S.P. (2001) Phytolith Trivia: John Lindley's Notes on Silex. The Phytolitharien. *Bulletin of the Society for Phytolith Research* 13 (2and3): 17

Kenoyer, J. M. (1998) *Ancient Cities Of The Indus Valley Civilization*. American Institute of Pakistani Studies, Oxford.

Kenoyer, J. M. (2008) Indus Civilization. In D. Pearsall (ed.) *Encyclopedia of Archaeology*. Academic Press, San Diego and Oxford, UK. pp.715-733.

Fullagar, R., T. Loy, and S. Cox (1998) Starch Grain Sediments and Stone Tool Function: Archaeological Evidence for Plant Foods In R. Fullagar (ed.) *A Closer Look: Australian Studies of Stone Tools*. SUAMS 6. Archaeological Computing Laboratory, Sydney. pp.49-60.

Loy, T. (1994) Methods in the Analysis of Starch Residues on Prehistoric Stone Tools. In J.G. Hather (ed.) *Tropical Archaeobotany: Applications and New Developments*. Routledge, London. pp.86-114.

Loy, T., M. Spriggs and S. Wickler (1992) Direct Evidence for Human Use of Plants 28,000 years ago: Starch Residue on Stone Artifacts from Northern Solomon Island. *Antiquity* 66: 899-912.

Madella, M. (1995) A Preliminary Study of Phytolith analysis, Agriculture and Use of Plants at Kot Diji, (Sindh, Pakistan). *Ancient Sindh* 2:93-108.

Madella, M. (2003) Investigating Agriculture and Environment in South Asia: Present and Future Contributions of Opal Phytoliths. In *Indus Ethnobiology: New Perspectives from the Field*, edited by S. Weber and W. Belcher pages 199–250. Lexington Books, USA

Meadow, R. (1989) Continuity and Change in the Agriculture of Greater Indus Valley: the Paleoethnobotanical and Zooarchaeological Evidence. In J.M. Kenoyer (ed.)*Old Problems and New Perspectives in Archaeology of South Asia*. Wisconsin Archaeological Reports, Madison. pp.61-74.

Meadow, R. (1996) The Origin and Spread of Agriculture in Northwestern and South Asia. In D. Harris (ed.) *Origin and Spread of Agriculture and Pastoralism in Eurasia*. UCL, Press, London. pp.390-412.

Nesbitt, M. (1995) Recovery of archaeological plant remains at Kaman-Kalehöyük," in T. Mikasa (ed.) *Essays on ancient Anatolia and its surrounding civilizations*, vol. 8, Bulletin of the Middle East Culture Centre in Japan. pp. 115-130.

Possehl, G. L. (2003) *The Indus Civilization: A Contemporary Perspective*. Altamira Press, New York.

Possehl, G. L. (1986) African Millets in South Asian Prehistory. In J. Jacobson (ed.) *Studies in Archaeology of India and Pakistan*. Oxford, IBH Publishing Company, New Delhi. pp.237-256.

Possehl, G.L. and M.H. Raval (1989) *Harappan Civilization and Rojdi*. Oxford and IBH and AIIS, New Delhi. Possehl,

Pearsall, D. M. (1988) Interpreting the Meaning of Micro-