

INDIAN ARCHAEOLOGY IN RETROSPECT

VOLUME III

ARCHAEOLOGY AND
INTERACTIVE
DISCIPLINES

Edited by

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MANOHAR

2002

Fifty Years of Archaeobotanical Studies in India: Laying a Solid Foundation

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INTRODUCTION

Archaeobotany is a composite discipline, combining botanical knowledge with archaeological materials. The archaeobotanist interprets evidence for human-environment interactions, especially as they pertain to food plants and agricultural activities. Archaeobotany is a young and fast-growing field. As a distinct and systematic enterprise it is younger than Independent India, but its roots penetrate the colonial substrate through its parental disciplines of archaeology and botany. It is my purpose in this chapter, both to trace the growth of this field within India and to highlight current trends and prospects. The archaeobotanical dataset is increasingly rich and recent interpretations of it promise to broaden our understanding of the human past.

After defining archaeobotany in terms of six data types, I briefly sketch the historical development of the discipline. It is possible to trace the growth of archaeobotany through both the quantity and quality of work. Progress through the accumulation of data is clear. This quantitative growth, however, should be understood through a series of qualitative phases (Section 2.1-2.3) in which the methods and interpretative paradigms of archaeobotany were transformed. Archaeobotany began as essentially a descriptive art, performed by a few respected and knowledgeable savants. It has become increasingly quantitative and self-critical, moving it towards a more professionalized and scientific discipline with constructive dialogue and an improved awareness of the limitations and potentials of its unique dataset. Aspects of archaeobotanical analysis which have recently been raised in South Asian publications, namely the application of crop-processing studies, quantification and the reconstruction of agricultural systems, are taken up in Sections 3.1-3.3. One area which still requires more explicit publication, in order to make archaeobotanical analyses replicable, is explicit concern with identification criteria and informative illustration (Section 4). A synthesis of the current evidence as it relates to the origins and spread of crops is provided in Section 5. Approaches to archaeobotany beyond the usual concern with seeds are sketched in Section 6, followed by some comments on theoretical issues (Section 7).

1. A DEFINITION OF ARCHAEOBOTANY AND ITS DATASETS

Archaeobotany is the study of plant remains recovered from or associated with archaeological sites. The study of these botanical remains has often been called palaeobotany (e.g. Sankalia 1975). While this is accurate in a broad sense, archaeobotany is a prefer-

able term, since it distinguishes itself by a focus on plant remains associated with the human past and with archaeological questions, i.e. those of an essentially cultural (including economic) nature. Palaeobotany is more often used to refer to the study of geological fossils for understanding the long term processes of plant evolution (e.g. Stewart and Rothwell 1993). Some workers have come to prefer the term palaeoethnobotany, since it adds the emphasis to the ethnological/human science aspects of the work (e.g. Weber 1991; Lone et al. 1993, in European and American contexts see J. Renfrew 1973; Pearsall 1989). This latter term is sometimes used to refer to the analysis and interpretation, while archaeobotany is used in a restricted sense to refer to the collection of data. Archaeobotany, in addition to being a shorter word, has the advantage of emphasizing the archaeological nature of the data, which should call attention to the exigencies of deposition, preservation and recovery.

Within archaeobotanical research, work can be divided on the basis of the different parts of the plant examined and types of preservation. Although they have not all been studied yet in India, six main lines of evidence can be considered as parts of archaeobotany: seeds, wood, charred parenchyma fragments, plant impressions, pollen and phytoliths. Additional kinds of evidence that are often subsumed within archaeobotany include residue analysis (based on microscopic structure, or identifying distinctive plant chemical products, see Heron and Evershed 1993) and diatom analysis (Battarbee 1988). These different datasets present significant differences and few scholars study all of them. Each derives from different parts of the plant and as a result has different potentials brought about by processes of preservation. Each of these six lines of evidence requires somewhat different techniques of study:

Seeds, which are the most common evidence of archaeobotanists, can be preserved by numerous means, including mineralization, waterlogging, metal oxide preservation (sometimes called pseudomorphs), or as impressions in pottery, although most often seeds are encountered as charred remains. These can generally be identified by examining their external morphology through a low powered binocular microscope (i.e. 6x to 40x). This line of evidence represents the bulk of archaeobotany and will occupy most of this paper. It has now become possible to extract genetic information (DNA) from ancient seeds, and the prospects of this technique are reviewed below (Section 6.5).

Wood charcoal is the most abundant component of archaeobotanical flotation samples. Given the centrality of fire in human cultures, wood charcoal is among the most numerous of cultural by-products. Wood can also be preserved under other circumstances, such as waterlogging (e.g. A. Ghosh 1941; Chowdhury and Ghosh 1946; S. Ghosh 1950). It is identified by looking at anatomical characters in transverse, tangential and radial sections. This kind of study requires higher magnifications, generally 50x to 150x, but sometimes as high as 400x (Section 6.1).

Parenchyma, the starchy storage tissue of plants, which predominates in tubers and other underground storage organs, can also be preserved by charring. Such material has not traditionally been searched for in archaeobotanical samples but studies have found it to be fairly common in a number of regions, including Europe, Southwest Asia, South

America, and the Pacific (Hather 1994a, 1994b; see also Pearsall 1989: 165-73; Hather 1994c). The potential of this line of evidence in India will be discussed below (Section 6.2). Identifications of this material require the high magnifications and depth of field provided by scanning electron microscopy (SEM).

Plant impressions, often preserved in pottery, are one of the traditional sources of archaeobotanical information. However, the study of impressions is often eschewed today when charred remains collected through flotation are available from a site. Impressions can be studied at lower magnifications and often latex casts are prepared from the moulds which can then be submitted to scanning electron microscopy (e.g. Stemler 1990). Most cereal parts such as chaff are preserved in pottery since these readily available by-products of grain production were often used for tempering pottery. Impressions represent the human-caused equivalent to geological plant impression fossils. Natural impression fossils from the Pleistocene are relevant to understanding the environmental context of human culture. Although little such evidence is yet available from South Asia, Korisettar et al. (1977) reported leaf impressions associated with Middle Palaeolithic tools. These specimens were briefly described, and require further examination for identification. Reliable determination of taxonomic affinities from leaf venation has largely developed during the past three decades (Hickey and Wolfe 1975; Hickey 1979).

Pollen is usually collected from geological sediments (palynology) for examining palaeoecology, which is often of relevance for archaeological interpretations. Of particular interest are approaches to identifying the introduction or intensification of agriculture through pollen (Section 5.6). In addition, pollen is sometimes preserved in archaeological sediments (archaeological palynology), and this topic is discussed separately in Section 6.3. The study of pollen requires chemical concentration and slide preparation for examination under magnifications ranging from 400x-1000x.

Phytoliths (sometimes called 'plant opals', silica skeletons, or spodograms) are the silica casts of plant cells formed by the evaporation of silica-laden water through plant transpiration. Being an inorganic glass, these have a high potential for preservation in many sedimentary environments although they are likely to be destroyed by mechanical processes. The study of these remains requires careful collection to avoid contamination by airborne phytoliths, as well as complicated chemical extraction techniques and magnifications from 400x to 1000x or even more (see Section 6.4).

2.1 A FIELD GERMINATES: THE CONSULTANT-PALAEOBOTANICAL PHASE (PRE-1947 TO 1974)

The earliest stage of archaeobotany in India (as elsewhere in the world) consisted of archaeologists sending the few and varied plant remains they had recovered to one botanist or another for identifications. The material recovered was generally small in quantity and collected unsystematically, whenever an excavator noticed a quantity of recognizable plant material, such as a ceramic vessel full of charred grain, or fortuitously preserved pieces of wood (e.g. Ghosh 1950). While this stage began prior to Independence, only

five sites had yielded samples, and the total number of plant taxa identified was only nine, three of which were forms of wheat (Table 1). Much of this pre-Independence work revolved around contradictory identifications of the wheat varieties recovered from Mohenjo Daro, Chanu Daro and Harappa (Stapf 1931; Luthra 1941; Burts 1941; also see Section 3.1). Material was often sent to state agricultural officers (e.g. Kumar 1952; Anonymous 1960), who supplied a list of species, often without description or discussion to the archaeologist. In the two subsequent decades much work was carried out by Chowdhury and Ghosh, of the Forest Research Institute, Dehra Dun, who provided a certain emphasis on woods (Chowdhury and Ghosh 1946, 1951, 1952, 1954-5, 1957; Ghosh 1950, 1961; Ghosh and Lal 1958, 1961, 1963). It was these avocational archaeobotanists who began to document the identification process. None of the botanists was primarily concerned with archaeological material or the Quaternary, and such studies formed a minor sideline in careers distinguished for their work elsewhere, in particular for systematizing the anatomy of Indian woods (Chowdhury and Ghosh 1958), as well as contributing to a floristic history of India on a geological timescale, such as Chowdhury's (1965) discussion of Indian palaeobotany in relation to the emergent theory of plate tectonics. They were botanists and palaeobotanists in the strict, traditional sense of such titles.

Coming from a similar background was Vishnu-Mittre (known only by this single name), a pivotal figure in Indian archaeobotany. His earliest work, on which his first Ph.D. focused, was traditionally palaeobotanical. He studied in detail the palaeofloristics of a Jurassic fossil locality at Nipania, district Amrapara, in the Rajamahar Hills, Bihar, and produced systematic descriptions of fossil conifers, ferns (Pteridophytes) and two extinct groups, the Pentoxyleae and Bennetiales, as well as fossil pollen and spores (Vishnu-Mittre 1952, 1954, 1956, 1957a, 1957b). His work on fossil spores and pollen

TABLE 1. PRE-INDEPENDENCE ARCHAEOBOTANY: THE SITES AND SPECIES

Site	Species reported	References
Mohenjo Daro	Free-threshing wheat (<i>T. aestivum</i> and <i>T. compactum</i>), barley, dates (<i>Phoenix dactylifera</i>)	Stapf 1931; Luthra 1936
Chanu Daro	Free-threshing wheat (<i>T. sphaerococcum</i> and <i>T. vulgare</i> [= <i>T. aestivum</i>])	Shaw 1943
Harappa	Free-threshing wheat (<i>T. aestivu</i> , and <i>T. sphaerococcum</i>), barley, <i>Sesamum indicum</i> , melon (<i>Cucumis melo</i>), dates (<i>Phoenix dactylifera</i>)	Burts 1941; Luthra 1941; Vats 1941: 467
Khokhrakot (Early Historic)	Rice (<i>Oryza sativa</i>), naked barley (<i>Hordeum vulgare</i> var. <i>nudum</i>)	Sahni 1936
Arikamedu (Early Historic)	3 wood species; 2 fruit spp.: coconut (<i>Cocos nucifera</i>), palmyra palm (<i>Borassus flabellifer</i>)	Chowdhury and Ghosh 1946

NOTE: Wheat species level identification are suspect (see Section 3.1)

TABLE 2. Archaeobotanical seed findings: sites sampled without flotation. Based on archaeobotanical reports (some casual reports of plant finds excluded, including numerous reports of rice alone from Chalcolithic, Iron Age and Early Historic sites). Sites from which plant impressions have been studied are also included. Taxa recovered are abbreviated in the fifth column by category, followed by alphabetical abbreviations of genus: C (cereals/possible cereals): C1 (*Coix lachryma-jobi*), Ec (*Echinichloa*), El (*Eleusine*), H (*Hordeum*), O (*Oryza*), Pa (*Panicum*), Pe (*Pennisetum*), Ps (*Paspalum*), Se (*Setaria*), So (*Sorghum*), T (*Triticum*). P (pulses): C (*Cicer*), La (*Lathyrus*), Lb (*Lablab*), Le (*Lens*), M (*Macrotyloma*), Pi (*Pisum*), V (*Vigna radiata/mungo*). Vu (*Vigna unguiculata*) O (others): Ab (*Ablemoschos*), Ar (*Artocarpus*), Br (*Brassica*), Cc (*Curcubitaceae*), Co (*Coriandrum*), Cr (*Carthamus*), Ct (*Citrus*), G (*Gossypium*), Ln (*Linum*), Mf (*Myristica fragrans*), Ph (*Phoenix*); Pv (*Papaver*), Rc (*Ricinus*), Sm (*Sesamum*), Tf-g (*Trigonella fenugraecum*), Vv (*Vitis vinifera*), Z (*Ziziphus*), ff (other fruits/nuts, with no. of taxa), ww (misc./weeds, with no. of taxa). Taxonomic nomenclature revised as per Tables 5-9 and Section 5. Dates are indicated by the following conditions. bc= dates based on radiocarbon age as reported (often 5570 half-life); bc= dates based calibrated radiocarbon timescale and/or historical chronology; some sites are dated based purely on relative terms by comparison with other dated sites, these probable dates are given in parentheses. *Bracketed taxa represent uncertain/unlikely identifications*. In some cases possible identity of unlikely identifications is indicated by ?=. Some taxa of uncertain crop/weed status are enclosed in parentheses.

Site	Map No.	Period	No. of Samples	No. of Seed Taxa (impressions)	Categories and Taxa	Reference
Ahar, Rajasthan	24	Chalcolithic (to Early Historic)	?	(2)	C: O [So]=?Ec	Vishnu-Mittre 1969
Atranjikhhera Uttar Pradesh	13	OCP to BRW 2000-1000 bc PGW Phase 1000-500 bc NBPW Phase 500-250 bc	?	4 5 6	C: H O P: C La C: H O T P: C La C: H O T P: C La V	Chowdhury et al. 1977, 1983 Chowdhury et al. 1977, 1983 Chowdhury et al. 1977, 1983
Bhatkuli Maharashtra		Kushan (Early Historic, 250 bc-300 AD)	1	2	C: O O: ww	Kajale and Deotare 1993
Bhokardan, Maharashtra	58	Early Historic, (250 bc-300 AD)	20	14 spp.	C: So P: C C: [Ei] So T P: C Cj La Lb Le Pi V O: Z ff(1) ww(2) C: O	Vishnu-Mittre and Gupta 1968b Kajale 1947b
West Bengal sites: Baidipur, Dt. Mayurbhanj; Barudih, Dt. Singhbhum	51, 50	Neolithic (2500-1500 bc?)	?	(1)	C: O	after Vishnu-Mittre 1968c
Bir-Kot-Ghwandai, Swat	5	late Chalcolithic, c. 1700-1400 bc	?	5 spp.	C: A H O T P: Le	Costantini 1987
Chanu Daro	56	Harappan (2600-2000 bc)	2	3	C: H T P: Pi	Vishnu-Mittre and Savithri 1982
Chirand, Bihar	45	Neolithic	6(?)	8	C: H O T P: La Le Pi V O: ff(1)	Vishnu-Mittre 1972; Vishnu-Mittre and Savithri 1976
Dangwada, Dt. Ujjain, Madhya Pradesh	59	Chalcolithic (=Malwa/Ahar, 2000-1500 bc) Early Historic (300 bc-300 AD)	?	6 5	C: O T P: Le V O: Z C: O T P: La Le O: Z	Vishnu-Mittre et al. 1984
Daulatpur, Haryana	22	(2200-1700 bc)	1	1 (+1)	C: O P: V	Vishnu-Mittre and Savithri 1982, 1985

(contd.)

Site	Map No.	Period	No. of Samples	No. of Seed Taxa (impressions)	Categories and Taxa	Reference
Ghaleghay, Swat	6	Chalcolithic I, c. 3000-2500 B.C.	6 (?)	1	O: ff (1)	Costantini 1987
		Chalcolithic II, c. 2500-1900 B.C.	1 (?)	4 + (1)	C: (O) T O: ff (1) ww (2)	
		Chalcolithic III, c. 1900-1700 B.C.	1 (?)	1 + (1)	C: H (O)	
Gufkral, Kashmir	2	c. 1200 B.C.	?	9	C: H O T P: Le Pi O: Vv ff (2)	(after Kajale 1989c)
Hallur, Karnataka	73	Neolithic-Iron Age (c. 1000 B.C.)	6	4	C: [El]=? Se O [Pa] O ff (1)	Vishnu-Mittre 1971 Kajale 1989a; Kajale and Deotare 1993
			1	6	C: O P: Lb M V O: Z	
Hulas, Dt. Saharanpur, U.P.	12	Late Harappan (1800-1300 B.C.)	?	19	C: [El]=Se H O So T P: C La Le M Pi V Vu O: Cc G Rc ff (2) ww (3)	Saraswat et al. 1992; Saraswat 1993
Hulaskhera, Dt. Lucknow, U.P.	32	(800 B.C.-500 A.D.)	?	27	C: (Ec) [El] H O P: V O: ww (22)	Saraswat and Chanchala 1994; Saraswat 1992
Inamgaon, 1971 season	71	Chalcolithic (Malwa, Late and Early Jorwe)	78	14spp. + 8 indet.	C: H O So T P: La Lb Le M Pi V V O: Z ff (2) ww (1)	Vishnu-Mittre and Savithri 1976
Kalibangan	81	Harappan (2600-2000 B.C.)	3 (+3)	4 (+1)	C: H T P: C Pi	Vishnu-Mittre and Savithri 1975; 1982 Kajale 1990c
Kaothe	92	Chalcolithic, c. 1900 B.C. (antiquity of seeds uncertain)	45	8 + 2 indet.	C: Pe Se So P: M V O: Sm Z ww (3)	
Kaundinyapura, Maharashtra	38	Early Historic Medieval	4		C: O	Vishnu-Mittre 1968b
			1	(Maize)	P: La Pi O: Z	
Kayatha, Madhya Pradesh	91	Chalcolithic (2500-1400 B.C.)	?	1?	C: T	after Vishnu-Mittre 1968c, 1977 Vishnu Mittre et al. 1985
			?	2	C: T P: M	
Khairadih, Dt. Balia, U.P.	33	Iron Age (700-200 B.C.)	?	12	C: H O T P: C La Pi V O: Mf Vv ff (3)	Saraswat et al. 1990
Koldihwa, Dt. Allahabad, U.P.	29	Neolithic (2500-1500 B.C.)	4 (?)	1	C: O	Vishnu-Mittre and Savithri 1979c
Lal Qila, U.P.	11	(1800-1200 B.C.)	16	5	C: H O T O: Cc ww	Kajale and Deotare 1993
Loebanr 3	4	late Chalcolithic, c. 1700-1400 B.C.	10	13spp.	C: H O T P: Le Pi	Costantini 1987
					O: Cc Ln V ww (6)	
Lothal Gujarat	10	Chalcolithic, per. II. 2350-2200 B.C.	?	(1)	C: O	Ramesh Rao and Lal 1985

(contd.)

Site	Map No.	Period	No. of Samples	No. of Seed Taxa (impressions)	Categories and Taxa	Reference
		Chalcolithic, per. IV 2000-1900 B.C.	1	(2)	C: Se O: Sm	
Magha, Dt. Mirzapur, U.P.	42	Black and Red Ware (1200-600 B.C.)	?	(4)	C: (Ec) O (Ps) O: ww (1)	Vishnu-Mittre et al. 1984
Mahagara, Dt. Allahabad U.P.	30	2000-1300 B.C.	?	2	C: H O O: ww (1)	Vishnu-Mittre et al. 1984; Saraswat 1992
Mahorana, Dt. Sangrur, Punjab	82	Early Bara Culture (2300-2000 B.C.)	1	4	C: H T P: Le O: Vv	Vishnu-Mittre et al. 1986b
			1	1	P: Lb	Saraswat and Chanchala 1994
Manjhi, Dt. Saran Bihar	25	Early Historic (250 BC-250 A.D.)	?	9	C: [E] H O T P: La Le Pi V O: Vv	Saraswat and Chanchala 1997
Mohenjo Daro	55	Harappan (2500-2000 B.C.)	1	4	C: H T P: Pi O: Br	Vishnu-Mittre and Savithri 1982
Nausharo, Baluchistan, Pakistan	54	Harappan (2500-2000 B.C.)	4 (?)	13	C: H T P: Le O: Ln Ph Vv Z ff (1) ww (2)	Costantini 1990a
Navdatoli, Maharashtra	70	Chalcolithic	256	13spp.	C: O T P: La Le V O: Z ff (2) Ln ww	Vishnu-Mittre 1961
Nevasa, Maharashtra (1954-6 season)	62	Early Historic 150 B.C.-200 A.D.)	30	17	C: [E] O Pe Ps So T P: C La Lb Le M Pi V O: Co Cr G Z	Anonymous, in Sankalia et al. 1960: pp. 529-30
(1959-60 season, and 1973 sampling)		Early Historic 150 B.C.-200 A.D.	?	16 + 2 indet	C: E] H O [Pe] Ps So T P: C Cj La Lb Pi V O: Cr Z ff (1) ww (3)	Kajale 1977b
		Early Historic?	1	5	C: O P: La Pi V O: Z	Vishnu-Mittre et al. 1985
Noh, Rajasthan	14	Iron Age- Early Historic	4	4	C: H O P: M V	Vishnu-Mittre and Savithri 1974
Pandu Rajar Dhibi, W. Bengal	52	c. 1000 B.C.	?	2	C: O T	after Vishnu-Mittre 1968c; 1977
Paunar, Maharashtra	69	Early Historic	?	2	C: O So	Vishnu-Mittre and Gupta 1968a
Peddarnadiyam, Andhra Pradesh	96	c. 1700-1300 B.C.	3	2spp. (+ unID)	P: Cj O: Ab	Venkatasubbaiah and Kajale 1991
Pirak, Baluchistan	7	Post-Harappan (1950-1550 B.C.)	?	11spp	C: A H O Pa [So] T P: C O: Ln	Costantini 1979
Radhan, U.P.	16	Painted-Grey Ware, Northern Black Polished Ware	1	4 spp.	C: H O P: [Le] Pi	Kajale and Lal 1988, 1989; Kajale and Deotare 1992

(contd.)

Site	Map No.	Period	No. of Samples	No. of Seed Taxa (impressions)	Categories and Taxa	Reference
		Medieval	1	4 spp.	C: H O T P: [Le] C: o	Ghosh and Lal 1963
Rangpur, Gujarat	9	IIA, 2500-2000 B.C.	Impression	(1)		Ghosh and Lal 1963
Rangpur		III 2000-1700	1	1 (+1)	C: O Pe	Ghosh and Lal 1963
Runjia, Dt. Ujjain, Madhya Pradesh		Sunga Period	1?	1	C: T	Vishnu-Mittre et al. 1984
Rupar, Dt. Ambala Punjab	19	Harappan/Baran (2500-1700 BC)	?	2	C: [Ps] T	Vishnu-Mittre and Savithri 1979a
Sanghol, Dt. Ludhiana Punjab	20	Kushana (0-400 AD)	?	9	C: H O So T P: Le M Pi V O: Z	Saraswat et al. 1992
		Late Harappa/Bara (1900-1400 BC)	?	25	C: H Se So T P: La Lb Le M Pi O: Cr Ln Pv Sm ww (10) ff (2)	Saraswat and Chanchala 1997
Senuwar, Dt. Rohtas, Bihar	21	Neolithic (2000 BC-1400 BC)	?	10	C: H O Ps T P: C La Le Pi V O: ww	Saraswat et al. 1992
		IA (2000-1800 BC)	?	20	C: Cl [Ei] H O Se So T P: La Le Pi O: Z ww (8) ff (1)	Saraswat et al. 1995
		IB (1800-1200 BC)	?	24	C: H O Ps Se So T P: C La Le Pi V O: Z ww (12)	
		II (1200-600 BC)	?	22	C: H O Ps Se So T P: C La Le Pi V O: Cr Ln Sm Z ww (6)	
Shikarpur, Kachchh	84	Harappan (2500-2220 BC)	?	11	C: [Ei] T Se O: Z ww (7)	Saraswat et al. 1995
Singh-Bhagwantpur, Dt. Rupnagar, Punjab		(1100-800 AD)	?	2	C: T O: G	Vishnu-Mittre et al. 1984
Surkotada	90	Harappan/Post-Harappan (2500-1700 BC)	3 from 1 locus (740 seeds)	28	C: [Ei]?=Se Se P: ww (25)	Vishnu-Mittre and Savithri 1978, 1979b, 1982; Vishnu-Mittre 1990
Taradih	102	Neolithic (to Late Historical, beginning c. 2000-1500 BC?)	?	6	C: H T P: C Pi V O: Z	Kajale 1991
Tekkalakota, Karnataka	93	Neolithic (?2000-1500 BC)	?	3	P: M [Ph]?=Lb O: Z	Vishnu-Mittre and Savithri 1979a
Ter, Maharashtra	64	Early Historic (200 BC-400 AD)	30	12	C: H O Ps T P: C La Le M Pi V O: Z [Rc]?=legum.	Vishnu-Mittre et al. 1971
Watgal, Karnataka	94	IIA (2800-2300 BC)	?	3 reported	C: [Ei] P: M O: <i>Areca</i>	Devaraj et al. 1995 (prelim. site report)
		2800 BC-1000 BC	?	?	C: H Pa Se P: M O: Z	Kajale 1998 (abstract)

was further stimulated by the pioneering palynologist Gunnar Erdtman, who stayed briefly at the BSIP [Paleobotanical Institute] in Lucknow as a visiting scholar and helped Vishnu-Mittre establish a comparative collection of modern Indian species, and to publish clear terminology for spore and pollen descriptions (Erdtman and Vishnu-Mittre 1956; Vishnu-Mittre 1957c). Having thus distinguished himself, Vishnu-Mittre was awarded a scholarship to pursue a second Ph.D. in Cambridge (Gupta 1994). There he studied Quaternary palynology, completing a Ph.D. on Holocene vegetation change in Cambridgeshire, England (Vishnu-Mittre 1960) under the supervision of Sir Harry Godwin, whose *History of the British Flora* (1956, 1975) laid much of the foundations for British archaeobotany. Vishnu-Mittre's work on the English Quaternary introduced him to the confounding factors of climate change and human intervention in the landscape in the interpretation of Quaternary plant remains, exemplified by the still contentious problem of the catastrophic decline of elms in Britain more or less contemporary with the advent of the Neolithic (Vishnu-Mittre 1965b; for more recent reviews, Scaife 1988; Peglar 1993). Vishnu-Mittre returned to India with interest both in plant evolution (e.g. Vishnu-Mittre 1963) and anthropogenic environmental change. Determined to make positive contributions to the understanding of Quaternary plant evolution and human prehistory, he began a programme in Kashmir of investigating Holocene pollen sequences (Vishnu-Mittre et al. 1962; Vishnu-Mittre and Sharma 1966; Vishnu-Mittre 1966, 1968a), and macrofossils (Vishnu-Mittre 1965a), as well as modern pollen rain (Vishnu-Mittre and Robert 1971). He clearly expressed the potential of pollen for isolating anthropogenic influences on vegetation including the introduction of agriculture in his paper 'Inter-relationship between archaeology and plant sciences' (1968a). Unfortunately the pollen sequences collected in Kashmir during this period were not radiometrically dated, so although they provide a relative sequence of vegetation changes including a likely period for the adoption or intensification of agriculture, they could not be correlated with archaeological phases (Agrawal 1992: 132). Equivalent pollen sequences were subsequently obtained from the Kumaon region which suffered from a similar lack of fixed chronology (Gupta 1975a).

It was during this period (1960s) that Vishnu-Mittre was first called upon to examine archaeobotanical material, consisting of charred lumps of seeds, plant impressions in pottery and mineralized remains preserved in the iron oxide of iron artefacts. His first archaeobotanical publication was a detailed report on material from Chalcolithic Navdatoli (Vishnu-Mittre 1961), in which he identified 13 species from amongst 256 hand-collected charcoal samples. This was the largest number of species identified to that date from an archaeological site, and Vishnu-Mittre used this data to produce the first synthesis of prehistoric Indian agriculture. Although the amount of data available at that time was small, one pattern which was clear was the gradual spread of wheat from the northwest towards the east and south. As more data accumulated, in large part through his own work, Vishnu-Mittre produced additional syntheses of archaeobotany (1968c, 1974, 1977).

Further interpretation of archaeobotany remained quite limited at this stage. The early work had simple taxonomic aims and produced lists of species, which resulted in a vaguely

defined study of 'past agriculture' and 'food habits' (Kajale 1974a: 55). As basic components of research, these objectives remain prominent today. Additional interpretation largely focused on plant remains as evidence of past knowledge about plant properties, such as the building properties of various woods (e.g. Chowdhury 1970), or simply the past possession of the knowledge of cultivation: the origins of agriculture was seen simply as a great scientific discovery (e.g. Chowdhury 1969; Vishnu-Mittre 1970b). In some cases archaeobotanical data were combined with geological palaeobotany in discussing the evolution of particular plant groups without giving consideration to the social and cultural associations of the archaeological finds (e.g. Gupta 1975b). In addition, basic ecological assessments were made on the basis of species present, especially trees represented in charcoal, in order to determine whether the environment had varied in the past. The bulk of such assessments concluded that past plant communities around a site were essentially similar to those of today (e.g. Chowdhury and Ghosh 1955; Lal 1963). Little interest was shown in what social patterning might be present in the data nor in the extent to which cultural factors might have encouraged either the adoption of agriculture or other changes in species present in particular regions through time. This narrow approach to plant remains developed in part because specimens were undertaken by botanists lacking expertise in archaeology and anthropology, and in part because of the cultural-historical theories which held sway in archaeological thinking. Archaeological cultures were defined and compared on the basis of checklists of artefact traits, so plant remains too were grouped by site and broad periods. The first assessments of the South Asian archaeobotanical record, which came out close to the end of India's second decade as an independent nation (Chowdhury 1970; Vishnu-Mittre 1968b, 1974), discussed plant domestication in terms of earliest occurrences of crop plants, without systematic consideration of the possible morphological changes involved, or the human activities which would have produced them. Finds from subsequent periods attested to the spread of cultivars, assumed to occur primarily through human migrations. When it was discussed, domestication was described as a typological shift from 'wild' to 'domestic' plants, and their co-occurrence was taken to imply domestication. For example, Vishnu-Mittre (1971) claimed to have identified both domestic finger millet, *Eleusine coracana* (Indian *ragi*) and a wild relative *E. indica* together from Late Neolithic/Iron Age Hallur, Karnataka. However, this claim is dubious on account of both probable mis-identification (see Section 4.2) and strong botanical evidence for an East African origin of finger millet, from a species of *Eleusine* distinct from *E. indica* (see Section 5.2). A similar approach to identify local domestication through co-occurrence was suggested for rice from Belan Valley sites (Sharma et al. 1980; see Vishnu-Mittre 1989).

Over the years the collection of archaeobotanical data became more frequent as archaeologists became increasingly interested in issues relating to plants, especially the origins of agriculture. The consultant-palaeobotanist phase of archaeobotany was greatly encouraged by the burgeoning archaeological research in peninsular India by researchers from Deccan College, Pune, under the guidance of H.D. Sankalia, a guiding light in post-Independence Indian archaeology (e.g. Vishnu-Mittre 1961, 1968a, 1971). As archaeo-

botanical studies increased, their results had a proportionately increased impact on scholarly views of Indian prehistory. It was this increased demand by archaeologists for botanical consultants that ultimately led to the emergence of the small number of vocational archaeobotanists, specializing only in archaeological plant remains.

2.2 PHASE TWO: FLOTATION AND THE ESTABLISHMENT OF PROFESSIONAL ARCHAEOBOTANISTS (1974-88)

Increasing archaeobotanical evidence from consulting palaeobotanists in the early 1970s corresponded to increased theoretical interest in Indian archaeology, especially within the processual mode of thought, which emphasized cultural ecology and settlement-subsistence systems (e.g. Dhavalikar and Possehl 1974; see Fuller and Boivin, Vol. IV of this series). This led to an increased interest in information on ancient agriculture and environment, and encouraged the growth of archaeobotany. A number of archaeobotanists began their careers during this period. M.D. Kajale at Deccan College produced an important review of the then available evidence (Kajale 1974a) and took up a programme, of sampling at Inamgaon and other excavations. Under the tutelage of Chowdhury, G.M. Buth and K.S. Saraswat entered archaeobotany (e.g. Buth and Chowdhury 1971, 1973; Buth and Saraswat 1972; Chowdhury et al. 1977). During this period, Vishnu-Mittre devoted himself increasingly to the study of archaeological plant remains and took on students of his own, most notably R. Savithri (e.g. Vishnu-Mittre et al. 1971; Vishnu-Mittre and Savithri 1974, 1975, 1976, 1978, 1979, 1982), as well as Chanchala and Saraswat who had come to the Birbal Sahni Institute in Lucknow. This period can be considered the professionalization of archaeobotany. Archaeobotany took on a new status as an integral part of archaeological research in India with the inclusion of a section on 'Palaeobotanical and Pollen Analytical Investigations' in the Archaeological Survey of India's annual *Indian Archaeology—A Review* since 1974-5 (Vishnu-Mittre and Savithri 1979a).

An important new technique, sampling through flotation, was adopted on several sites in South Asia during the later 1970s. Developed in America and Europe in the 1960s initially as a laboratory technique, flotation was transferred to fieldwork situations with the growth of problem-oriented research on the origins of agriculture (Streuver 1968; Helback 1969; Jarmon et al. 1972; Stewart and Robertson 1973; for a more detailed review see Pearsall 1989: 19-79). As noted by Kajale (1974a), smaller, less conspicuous seeds could easily be missed in collections made by hand. In 1973, Glover carried out flotation in Island Southeast Asia at Sulawesi (Glover 1979). Flotation was first carried out in India at Daimabad, Naikund and Inamgaon (Kajale 1977a, 197b, 1982, 1988b), and soon came to be applied in a research programme on the Neolithic of Kashmir (Buth et al. 1982, 1986) and later Narhan in the Ganga plains (Saraswat et al. 1994), as well as some Harappan sites (see Table 3, for a comprehensive list of floated sites in South Asia). With flotation, the increase in the amount of botanical data from a single site, even a single trench, increased so dramatically that it requires full-time specialists to work through

TABLE 3. Sites sampled by means of flotation. Taxa recovered are abbreviated in the fifth column by category, followed by alphabetical abbreviations of genus: C (cereals/possible cereals): Av (*Avena*), Cl (*Coix lachryma-jobi*), Ec (*Echinochloa*), El (*Eleusine*), H (*Hordeum*), O (*Oryza*), Pa (*Panicum*), Pe (*Pennisetum*), Ps (*Paspalum*), Se (*Setaria*), So (*Sorghum*), T (*Triticum*). P (pulses): C (*Cicer*), La (*Lathyrus*), Lb (*Lablab*), Le (*Lens*), M (*Macrotyloma*), Pi (*Pisum*), V (*Vigna radiata/mungo*), Vu (*Vigna unguiculata*). O (others): Ab (*Ablemoschos*), Ar (*Artocarpus*), Br (*Brassica*), Ca (*Carthamus*), Cc (*Cucurbitaceae*), Ln (*Linum*), Ph (*Pheonix*); Rc (*Ricinus*), Sm (*Sesamum*), Vv (*Vitis*), Z (*Ziziphus*), ff (other fruits/nuts, with quantity), ww (misc./weeds, with quantity); rh (rhizomes). Taxonomic nomenclature revised as per Table 5 and Section 5. Dates are indicated by the following conditions. bc= dates based on radiocarbon age as reported (often 5570 half-line); bc= dates based calibrated radiocarbon timescale and/or historical chronology; some sites are dated based purely on relative terms by comparison with other dated sites, these probable dates are given in parentheses. *Bracketed taxa represent uncertain/unlikely identifications, while parenthetical taxa are of unclear crop/weed status.* In some cases possible identity of unlikely identifications is indicated by =. Some taxa of uncertain crop/weed status are enclosed in parentheses.

Site, State	Map No.	Period	No. of Samples	Taxa Reported	Categories and Taxa	Reference
Adam, Maharashtra	65	Microlithic (2000-1500 bc)	2	1	C: O	Kajale 1994
		Chalcolithic 1900-900 bc	3	1	O: Z	
		Iron Age (100-500 bc)	5	2 + 3 indet.	C: O P: La	
		Pre-Mauryan (c. 500-300 bc)	2	8 + 9	C: [Cl] O Se P: Lb Le M V O: Z ww (9)	
		Mauryan (300 bc-50 AD)	2	9 + 2	C: H O T P: La Le Pi V O: Ab Z	
Bhadra (50-150 AD)	2	7	C: Cl O P: La Lb Le Pi O: garlic			
Allhadino, Sindh	88	Harappan, c. 2500-2000 bc	?	3	C: H T P: ?	Fairservis 1982
Apegaon, Maharashtra	103	1600-1000 bc	11	10	C: H T P: La Lb Le M Pi V O: Z	Kajale 1979
Bubar Kot, Gujarat	86	2000-1700 bc	200	23	C: [El] Pa [Pe] Se P: La Le V O: Br Ln ww (14)	Reddy 1994
Balakot	89	Harappan, c. 2500-2000 bc	?	1 (+ pollen)	C: H pollen: Cc G	cf. Dales 1986; McKean 1983
Balathal, Rajasthan	23	Chalcolithic (2350-1800 bc)	?	22 + 4 indet.	C: Cl H Pa Se T P: [C] P V O: Ab Cc [Ln] Z ww (8)	Kajale 1996a
		Early Historic (500 bc-300 AD)	?	25 + 4 indet.	C: Cl H O Pa Ps Se T P: C Pi V O: Ab [V] Z ww (5)	
Balijapalle, Andhra Pradesh	98	Neolithic (1700-1300 bc)	10	1 + 5 indet.	O: Ab ww (5)	Venkatasubbaiah and Kajale 1991
Beli-Lana, Sri Lanka		Mesolithic 10000-8000 B.P.	?	3	O: ff (3)=Ar, Musa, <i>Canarium</i>	Kajale 1989b
Bhagimohari, Maharashtra	72	First Millennium bc	15	13 + 2 indet.	C: (Cl) H O P: Cj La Lb Le M Pi V O: Z ww (4)	Kajale 1989c; Kajale and Deotare 1992
Burthana Tigrana	18	2500-2000 bc		5	C: H T P: M V O: Z	Willcox 1992

(contd.)

Site, State	Map No.	Period	No. of Samples	Taxa Reported	Categories and Taxa	Reference
Burzahom, Kashmir	3	I 2400-1700 BC	?	12	C: H T P: Le Pi O: ff (3) ww (5)	Lone et al. 1993
		II 1700-1000 BC	?	10	C: H T P: Le O: Vv ff (4) ww (3)	
		III 1000-600 BC	?	14	C: H O T P: Le Pi O: ff (4) ww (5)	
		IV 600 BC- 200 AD	?	17	C: H O T P: Le Pi O: ff (5) ww (7)	
Daimabad, Maharashtra	63	Savalda (2000-1700 BC)	?	3	C: H P: Le O: Z	Kajale 1977a
		Malwa (1700-1500 BC)	?	7	C: H T P: La Le M Pi O: Z	Kajale 1977a
		Jorwe (1500-1100 BC)	?	14	C: [Ei] H O Ps So T P: La Le M Pi V O: Cl Ln Z	Kajale 1977a
		Savalda (2000-1800 BC)	14 total, for all periods included above	2	C: H T	Vishnu-Mittre et al. 1986
		Malwa (1700-1500 BC)	20	C: [Ei]=? Se H T P: La Le M Pi Vu [Ph]=Vu O: Z ww (10)	Vishnu-Mittre et al. 1986	
Jorwe 1500-100 BC)	included above	18	C: [Ei]=? Se H Ps Se T P: La Le M Pi Vu [Ph]=Vu O: Z ww (6)	Vishnu Mittre et al. 1986		
Damdama, Pratapgarh, U.P., Hallur, Karnataka	31 73	Mesolithic (4th M. bc?) Neolithic	14 prelim. 6	8 + 3 indet. 10+	C: [O] O: ww (10) C: H O T Ec Se Pa P: Lb Le M V O: ww parenchyma	Kajale 1990a; Kajale and Deotare 1992 Fuller et al. forthcoming
Hanumantharao-peta, Andhra Pradesh	99	Neolithic	prelim. 1	4+	C: Ec Se P: M V O: ww parenchyma	Fuller et al. forthcoming
Harappa	7	2400-2350 BC	(100s)	7+	C: H T P: C La Le Pi O: Z ww	Miller and Reddy 1990; Weber 1997
		2200-2000 BC	(100s)	9+	C: H O T + 'millet' P: C La Le Pi O: Z ww	
Inamgaon, Maharashtra	71	Malwa 1700-1500 BC	186 total	33	C: [Ei]=? Se H T P: Lb Le M Pi O: ff (4) ww (9) Cc	Kajale 1988b
		Early Jorwe 1500-1200 BC		30	C: [Ei]=? Se H Se T P: La Lb Le M Pi O: Ph [Sm] ff (6) ww (13)	
		Late Jorwe 1200-900 BC		31	C: (Cl) [Ei]=? Se H O Pa Se T P: C La Lb Le M Pi V O: Ph [Sm] ff (5) ww (10)	

(contd.)

Site, State	Map No.	Period	No. of Samples	Taxa Reported	Categories and Taxa	Reference
Kuntasi, Gujarat	101	Harappan 2500-2000 BC	?	?	C: [EI] H Se T O: ww	Kajale quoted in Dhavalikar 1995
Laduwala, Haryana	near 17, 18	2800-2300 BC	62 (from 5 [?] sites)	2	C: H O: Z	Willcox 1992
Mangali, Luduwala	near 17, 18	(1500-1900 AD)		12	C: H O [Pe] S T P: M V O: Cc G Ss Z Rh	Willcox 1992
Mitathal, Haryana	17	2000-1400 BC		7	C: H O T P: M V O: Z rh	Willcox 1992
Naikund, Maharashtra	75	1st M. BC	7	5	C: T P: Le Pi V O: Z	Kajale 1982
Narhan, Uttar Pradesh	44	Chalcolithic- Iron Age, c. 1300 BC- 200 BC	54	54	C: (Ec) H O (Pa) Pe Ps T P: C La Lb Le M Pi V O: Ar (Br) Ca (Cc) Ln Ph Ss Vv Z ww (33)	Saraswat et al. 1993; 1994
Oriyo Timbo, Gujarat	85		247	18	C: [EI] Pa Se P: V O: Br ww (13)	Reddy 1994
Peddarnadiyam, Andhra Pradesh	96	Late Neolithic 1700-1300 BC	prelim. 2	4+	C: Se P: M O: ww Parenchyma	Fuller et al. forthcoming
Ramapuram, Andhra Pradesh	97	Neolithic (2nd M. BC)	?	3	C: H P: Lb V	Kajale, IAR 1980-1
Rohira, Punjab	83	Harappan, (c. 2000- 1700 BC)	?	5	C: H T P: Le M O: Tf-g	Vishnu-Mittre et al. 1985
Rohira, Punjab		(2300-2000 BC)	Flot. 4	7	C: H So T P: Le M O: Ph Vv	Saraswat 1986
Rojdi, Gujarat	87	A: c. 2600- 2200 BC	74	22	C: [EI]?=Se H Pa Se P: V O: Z ww (12)	Weber 1991
		B: 2200- 2000 BC	59	31	C: [EI]?=Se HPa Se O: Ab (Br) Z ww (20)	
		C: 2000- 1700 BC	284	59	C: (Ec) [EI]? Se H Pa (Ps) Se So P: La Le M Pi V O: Ab (Br) Cc Ln ww (38)	
Sanganakallu, Karnataka	95	Neolithic	prelim. 6	9+	C: H T Se Pa P: Cj Lb M V O: Z ww parenchyma	Fuller et al. forthcoming
Semthan, Kashmir	1	I 1500-600 BC	?	8	C: H O T P: Le V O: ff (3)	Lone et al. 1993
		II 600 BC-200 BC	?	12	C: H O T P: Le Pi V O: ff (4) ww (2)	
		III 200-1 BC	?	11	C: Av H O Pa T P: V O: ff (3) ww (2)	
		IV 1-500 AD	?	17	C: Av H O Se T P: Le Pi V	

(contd.)

Site, State	Map No.	Period	No. of Samples	Taxa Reported	Categories and Taxa	Reference
		V 500-1000 AD	?	13	O: ff (3) ww (6) C: Av H O T P: Le Pi V	
Tarakai Qila, NWFP	100	chalcolithic 4th to 3rd M. BC	?	3	O: ff (3) ww (3) C: H T P: Le	Thomas 1983a, 1983b
Tuljapur Garhi, Maharashtra	68	Chalcolithic	9	15+2 indet.	C: H O So T P: C Cj La Lb Le M V	Kajale 1988a; Kajale 1996b
Veerapuram, Andhra Pradesh	78	500 BC- 400 AD	44	10	O: ww (5) C: H O Ps P: Lb M Pi V O: Cc Z ff (1)	Kajale 1984

all the material. Thus, with flotation, the feasibility of employing botanists only as consultants decreased. It was this rather rapid and revolutionary shift that facilitated future analytical refinements. With fulltime specialists it became possible to consider more carefully the unique nature of archaeobotanical data.

The impact of flotation on the scholarly understanding of ancient Indian agriculture was thus quite dramatic, as a greater number of species came to be identified, and previously attested species became more reliably recorded. A striking example is the case of barley. Barley has long been of interest to Indologists, as the cereal identified with the Sanskrit *Yava*, a cereal widely attested in the Rig Veda (*Rik Samhita*) and it was therefore often connected to the advent of the 'Indo-Aryans.' In relation to this hypothesis Vishnu-Mittre (1970a) reviewed the available evidence for barley, and concluded that it was of minor importance to the Harappans, nor were other archaeological cultures known in which it was a staple, and therefore it was not possible to identify any then sampled sites with the 'Aryans'. Similarly, in a review of the archaeobotanical record, barley was designated 'a distinctly extrapeninsular crop' (Kajale 1974a: 61). Both of the above generalizations, regarding barley as a staple crop and establishing its extra-peninsular distribution, have been clearly disproved by more recent archaeobotany. Indeed, barley is now one of the most widely documented crops on prehistoric sites in India, it is particularly prominent on Chalcolithic sites on the peninsula (see, e.g. Kajale 1988a, 1988b, 1991) and it is known from further south on later Neolithic sites (Fuller et al. n.d.; see Korisettar et al. in Vol. I of this series), Ganga Valley sites and numerous Harappan sites (Vishnu-Mittre and Savithri 1982; Saraswat 1992). This example illustrates the instability of generalizations based on a few haphazard hand-collected samples and the consequent need for flotation.

2.3 PHASE THREE: TOWARDS A SELF CRITICAL ARCHAEOBOTANY THROUGH FORMATION PROCESSES (1988-PRESENT)

For a more judicious use of archaeobotanical data it is necessary to be aware of the processes which brought them to the microscope of the specialists, including recovery, preservation and original depositional processes. The study of depositional and post-

depositional factors is called taphonomy, a term borrowed from palaeontology which entered the archaeological literature in the 1970s as increasing attention was paid to the formation of animal bone assemblages. The interest in taphonomic processes developed in archaeology alongside an awareness of pre-depositional factors influencing the formation of assemblages. Archaeobotanical formation processes started to become an issue in the early 1970s in the West after the advent of flotation, although it was some fifteen years before these issues began to be addressed in South Asian contexts.

An important observation was that most archaeobotanical remains represent a particularly limited range of ecological plant communities, most often that of arable fields, and therefore archaeological plant remains were most likely to relate to a limited range of human activities, most notably the harvesting and processing of crops (Knorz 1971; Hillman 1972). Dennell (1972) took a particular interest in estimating the relative 'value' or importance of the different plant species represented archaeologically. In order to do this he discussed different kinds of archaeological contexts from contemporaneous levels on a site in order to highlight the different depositional and preservational factors involved and their implications for understanding different economic activities. He divided these find-contexts into six main categories: (1) storage jars, storage pits, silos; (2) ovens, hearths; (3) floor deposits; (4) middens or rubbish pits; (5) impressions in pottery (not carbonized remains); and (6) fill deposits. In more recent reviews of archaeobotanical interpretation the importance of the *context* of recovery and the probable *source* (in terms of plant community and human activities) from which the plant came have continued to be emphasized (Pearsall 1988, 1989: 22-225; Kajale 1988b; Weber 1991). Dennell (1972, 1974, 1976) contrasted the assemblages recovered from floor deposits, ovens, and midden deposits from prehistoric Bulgarian sites and found that floor samples had higher proportions of weed seeds and generally smaller cereal grain sizes. He suggested that this came from sieving to remove weeds and accidentally some small grains, which contributed plant remains to floor deposits; oven and midden deposits were interpreted as discard after the grain had been cleaned. Although this study failed to address some problems, such as the question of how the floor deposits were charred, it was important for emphasizing the need to compare similar depositional contexts when making chronological comparisons.

The most common form of archaeological preservation is the carbonization of seeds (and other plant parts such as cereal chaff). Although earlier discussions were not always clear as to how carbonization was assumed to have occurred (including, e.g. Dennell 1972), and there was some belief in natural carbonization in the soil, it is now generally believed that in almost all cases preservation required exposure to fire (Minnis 1981; Hillman 1981, 1984; Pearsall 1989: 202, 224; Zohary and Hopf 1993: 3-4). Thus, as a rule of thumb for sites in most environments, excepting regions of extreme aridity and desiccated preservation, uncharred seeds are generally assumed to represent intrusive, modern contaminants in archaeobotanical assemblages (Pearsall 1989; Weber 1991). As charred grains themselves are not eaten, they must have entered the archaeological record incidentally, and the presence of cereal chaff, which is not eaten, together with seeds of

species known to occur as weeds in arable fields, drew attention to the probable roll of crop processing in forming archaeological assemblages (Hillman 1972, 1973; Dennell 1972, 1974, 1976). Hillman (1973, 1981, 1984) pioneered an ethnoarchaeological approach to studying the effects of crop-processing on assemblage formation through his work on traditional cultivation and harvesting of wheat and barley in Turkey. While his work focused on the presence and proportions of different chaff types, in addition to cereals and weeds, Glynis Jones (1983, 1984, 1987) took a different emphasis to her ethnographic study in Greece, in which she focused on the analysis of the weed components of assemblages in order to identify the various processing stages. Such crop-processing studies drew attention to some of the ways in which the remains of crops and their weeds could be routinely exposed to fire, as crop-processing by-products were used as fuel or disposed of in fires. Processing by-products are also frequently used as animal fodder, and therefore seeds can enter fires through the burning of animal dung (Miller 1984, 1991; Miller and Smart 1984; Bottema 1984; Thomas 1989: Fig. 6; Charles 1998). By the mid-1980s discussion of the formation of archaeobotanical assemblages, in particular the effects of crop processing, were a central part of European and Southwest Asian archaeobotany.

The study of formation processes made little impact in South Asian archaeobotany until the late 1980s, and consideration of crop processing was not seriously incorporated until the 1990s, and can be seen as part of a growing awareness of formation processes that developed in South Asian archaeology through the latter half of the 1980s (see Fuller and Boivin in Vol. IV of this series). Kajale (1988b), in his analysis of the evidence from Inamgaon, compared similar contexts from a number of levels, those from the fill and floors of excavated house structures. He found little significant difference, which he interpreted to indicate essentially uniform economic activities between households. However, could not such similarities in assemblages be the result of the same general formation processes of the site deposits and the incorporation of charred plant remains? To argue that the plant remains in a structure are a direct reflection of the activities in that structure one must assume more or less *in situ* deposition of charred plant remains resulting from human activities rather than the infilling of structures after their abandonment by secondary deposition of rubbish from elsewhere on the site. This example illustrates a problem of equifinality faced by those who interpret plant assemblages in which both human activities and the sedimentary processes on habitation sites affect the composition and location of assemblages. Kajale's report (1988b) also includes the first mention of cereal chaff in a South Asian archaeobotanical report, although it was absent from his samples. He takes its absence to suggest that crop-processing was not carried out in the excavated areas, but perhaps 'off-site' away from the habitation area, although such a claim is also marred by the confounding affects of preservation since chaff is less easily preserved than grains, assuming both regularly come into contact with fire in the first place.

Increasingly, a number of reports have at least discussed briefly the possibility that weed seeds represent the by-products of harvest and processing (e.g. Lone et al. 1993;

Saraswat et al. 1994; see also, Ratanagar 1989). Nevertheless, the insights of archaeobotanical taphonomy have been slow to enter most archaeobotanical discussions in South Asia and a 'utilization fallacy' continues. While Weber (1991) took notice of finding comparable contexts, he did not seriously consider the role of crop-processing or the potential contribution of dung-burning. The failure to consider these avenues of seed preservation probably derived from his American archaeobotanical background, as there was generally a lag in American archaeobotany in taking into account crop-processing (Hastorf 1988). Instead, American archaeobotany remained largely under the influence of a utilization fallacy in which most, if not all, recovered species were interpreted in terms of ethnographically documented uses and in terms of the vegetation surrounding a site in the past (e.g. Minnis 1981). Similar assumptions were also already established in Indian archaeobotany (e.g. Vishnu-Mittre and Savithri 1982; Vishnu-Mittre 1985).

In the past decade, the importance of crop-processing has become more widely recognized, and ethnoarchaeological studies of additional crop species have been undertaken. Thompson (1996) has discussed the variations in the processing of rice in Thailand, which includes many general processes relevant to the understanding of rice assemblages in other parts of the world. Within South Asia, the study of the millet processing sequences has been undertaken, by Reddy (1991a, 1994, 1997) in Andhra Pradesh and in Nepal by Lundstrom-Baudais (in press). In addition, Ruth Young (1998) has studied the processing of finger millet in Uganda. Even though it must be accepted that there is a range of potential cultural variations in these operations, many of the basic products and by-products of the processing stages are constrained by the morphology of the crop involved, thus studies in one part of the world can often be transferred to the same or a closely related species in another region (Hillman 1984). Detailed studies of pulse processing are largely lacking, although Butler (1992) supplied a basic framework for considering the cropping, harvesting and processing of traditional pulses in Turkey; in general the processing of pulses can be compared to that of free-threshing wheats.

There remain numerous directions for experimental and ethnoarchaeological research still to pursue to better understand archaeobotanical formation processes. First there are numerous crop types which have not been adequately studied in terms of processing sequences, notably pulses and oil seeds. Another important area for future consideration is the filtering effect of fire and how this may vary in different societies on the basis of customs relating to fire use and hearth-cleaning. The plant remains most often recovered archaeologically are those which have been charred. Thus rather than reflecting ancient plant use on site, the recovered remains represent only a fraction of those 'adventitiously scorched portion' (Saraswat et al. 1994: 256). Thus while the presence of plant remains in a particular soil sample is likely to be more a reflection of charring 'accidents' (Minnis 1981), how particular species repeatedly are subject to such accidents remains poorly understood. At issue is whether we see the archaeobotanical record as the accumulation of a large number of small accidents, which is perhaps more likely in general, or as the dispersal of the products of a few 'accidents' of a larger scale, such as the burning of a large quantity of by-products immediately after large scale threshing and winnowing (this latter case must be assumed in producer/consumer models).

3.1 APPLYING THE INSIGHTS OF CROP-PROCESSING: WEEDS, ARABLE ECOLOGY AND HUMAN ECONOMY

While most archaeobotanical discussion focuses on known food plants, especially crops, there are usually other plant species present in samples, and these are gaining increasing importance as sources of information on the past cultural behaviours. Traditionally, all seeds found on archaeological sites were assumed to represent either human resource use or 'natural' seed rain during occupation (e.g. Minnis 1981; Weber 1991: 16-19). However, considerations of taphonomy (see Section 2.3, above) suggest that most charred plant remains are likely to have originated in arable fields and are likely to have come onto site and into contact with fire through the repetitive activities of crop-processing and food preparation. Indeed, observations that most samples contain crops, often crop chaff, and other herbaceous species that are known to occur as weeds in fields today, led to the reasoning that the weed species could provide insights into the ecology of arable fields (e.g. Knorz 1971; M. Jones 1988a, 1988b; Hillman 1991; Behre and Jacomet 1991). Thus, in addition to using the weed types present in a sample to understand the stages of crop-processing waste represented by samples (Hillman 1981, 1984; G. Jones 1984, 1987; Reddy 1994, 1997; Thompson 1996), they have come to be considered as data for understanding ecological aspects of agriculture such as soil choice, tillage practices, weeding practices, and irrigation (e.g. Wasylikowa 1981; Hillman 1984, 1991; M. Jones 1988a, 1988b; Behre and Jacomet 1991; G. Jones 1992; G. Jones and Halstead 1995; G. Jones et al. 1995; van der Veen 1992).

Although Weber (1991: 134) recognized that 'weed species are important for our understanding of sowing and harvesting practices and soil fertility patterns', he did not apply this principle in his interpretation of the Rojdi data. Instead he interpreted most of his weedy taxa in terms of 'disturbance in and around a site'. Thus the increase in the number of weed species, and the overall density of weed seeds were taken as indicating increased land disturbance around site due perhaps to deforestation or other human impacts. Unfortunately, such a claim cannot be made from archaeobotanical samples if it is accepted that almost all of the charred seeds represent the incidental inclusions in harvested crops that get separated during crop processing. The changes seem more likely to represent changes either in cultivation practices or else a change in the harvesting/processing regime.

Weed seed assemblages can also provide insight into aspects of social organization, as it relates to crop-processing and storage. Several authors have suggested that it may be possible to distinguish sites with local cultivation, 'producer' sites, from sites which received their crops partially processed from elsewhere, 'consumer' sites, although there are serious problems with applying such models. Reddy's ethnoarchaeological models were applied in the analysis of archaeobotanical assemblages from two Late/Post-Harappan sites in Gujarat, Oriyo Timbo and Babor Kot, and she interpreted the lack of most predicted by-products from Oriyo Timbo as evidence that cultivation and preliminary processing were not carried out at this site (Reddy 1994, 1997). Similarly, Thompson (1996) has suggested the rice 'producer' and 'consumer' sites can be distinguished on the basis of archaeobotanical components. Both of these authors base their approach on

suggestions by Hillman (1981, 1984), that early processing stage remains should occur on producer sites. Such results are of interest although caution is warranted as there is significant disagreement within European archaeobotany as to whether the composition of by-products in wheat/barley assemblages can be used for distinguishing producer/consumer sites and if so how (M. Jones 1985; van der Veen 1992: 91-9; Stevens 1996). This issue hinges on how one assumes most plant remains came into contact with fire, whether as a result of the burning of processing by-products after the large-scale threshing and winnowing that follows harvest (implicitly assumed in producer consumer models, cf. Hillman 1981, 1984; M. Jones 1985; van der Veen 1992; Reddy 1997), or whether the repeated small-scale processing of crops taken from storage for daily consumption is a more likely route (shown to be the most likely situation for wheat/barley assemblages in prehistoric Britain by Stevens 1996). The difficulty, therefore in interpreting the lack of early processing stages as evidence of consumption without local cultivation, as Reddy (1994, 1997) argues to be the case for Oriyo Timbo, is that it ignores the possibility that cultivating, threshing and winnowing were carried out near but away from the central habitation area and that the products were not burnt. A more general concern with trying to apply a producer/consumer model to archaeobotanical evidence is whether it is actually realistic to expect village sites where no cultivation and crop-processing was carried out; the ethnographic situation in South Asian villages today suggests that all villages are involved in some amount of food production (Dilip Chakrabarti: personal communication). In the case of Oriyo Timbo, where evidence from cattle teeth suggests repeated, short seasonal occupations (Rissman 1986), it indeed seems likely that cultivation was not practiced locally, but this cannot unambiguously be argued from the archaeobotanical evidence. It is plausible that the population of this site was attached to another more permanent settlement where they were involved in cultivation activities.

Confounding factors that operate against the preservation of all by-products of all stages of the processing sequence. If it is assumed that most seed charring occurs as the result of daily processing of semi-clean stored crops, an attractive assumption since repetitive activities are more likely to produce constant archaeological remains distributed through a site, then the differences in processing stages represented by assemblages may have more to do with decisions about how much processing to do before storage of the crop, which in turn relates to scale of social organization for crop processing (Stevens 1996). If we take this perspective to the material from Rodji (Weber 1991: 135-8), then the change noted to have occurred between Rojdi B and Rojdi C, might be seen as a result of a change in the organization rather than any significant change in the actual cereal cultivated or their relative importance in diet (further discussion in Fuller and Madella in Vol. II of this series). The analysis of non-crop seeds for ecological and social information is a rapidly developing area of archaeobotanical research in many parts of the world, and offers great potential for South Asian archaeology, as the work by Reddy (1994, 1997) demonstrates.

There is no easy formula for interpreting the composition of crop/weed assemblages, but rather a number of consistent factors which need to be thought through for each

assemblage. Methods of harvesting, threshing, winnowing and sieving act to separate and group various plant parts, cereal grain, chaff and weed seeds. Only those weeds that are in seed at the time of harvest and are harvested enter the crop-processing filters. At this first filter the harvesting methods (uprooting, sickle reaping at mid-stalk or of individual cereal ears) interact with the growth habit of the weeds (and their seasonality in terms of fruiting) to determine which are harvested (Hillman 1984; Reddy 1994, 1997). Since different crop types are harvested differently, for example *Sorghum*, *Pennisetum* and *ragi* (*Eleusine coracana*) are often harvested by removing individual heads, whereas smaller millets with thinner stalks are gathered in groups and cut near their base (Reddy 1994, 1997), these different crops can be expected to bias weed assemblages in different ways. Another important factor, noted by Reddy (1994, 1997), is whether or not millets are free-threshing, as the case with *Sorghum*, *Pennisetum* and *Eleusine*, or retain an indurate lemma and palea that must be pounded and winnowed off, as in *Panicum*, *Setaria*, *Echinochloa* and *Paspalum*. These latter species therefore will always see more processing and may therefore have a greater likelihood of entering by-product assemblages. In addition, these hulled millets are sometimes parched with fire (or sun-dried) to aid the removal of the lemma/palea (Reddy 1994, 1997; Laundström-Baudais et al. in press); this provides another possible route to charring. The range of factors affecting pulse crops, which are also pounded and winnowed and can be harvested either by uprooting or picking individual pods, has yet to be considered seriously.

3.2 ARCHAEOBOTANICAL QUANTIFICATION

Another aspect of archaeobotanical analysis which has been discussed in the past decade is quantification. With the larger assemblages brought about by flotation it becomes necessary to summarize the data numerically in some way. In addition, with an awareness that archaeobotanical remains are not a straightforward reflection of human diet or activities, choosing ways to quantify one's evidence requires making assumptions about the relative significance of different factors in the formation of archaeological assemblages. Issues in quantification revolve around two problems: first, how do we compare the relative importance of different taxa present within a sample; and second, how do we compare the overall contents of different samples. Weber (1991, 1993) addressed the first of these concerns by comparing three common methods for quantifying abundance of archaeobotanical remains: density, percentage, and ubiquity. In general he found that each of the three measures tended to agree in the identification of the few most dominant species at the site of Rojdi, which were *Setaria*, 'Eleusine' (there is reason for concern over this identification, see Section 4.2), *Panicum sumatrense* (syn. *P. miliare*) and *Chenopodium album*. Density standardizes the number or volume of a taxon in a sample against the total volume of samples (usually of the total sampled sediment, but it could also be against the total charcoal or 'light fraction'), while 'percentage' calculates what percentage of the identified specimens in a sample belong to a given taxon. A potential problem with both of these approaches is that they do not take into account biases related

to a particular taxon, such as seed productivity which can vary greatly between species. Those taxa which produce more seeds, or are more likely to produce waste seeds during processing, will be consistently over-represented. Thus it is generally accepted that relative frequencies alone do not lead directly to conclusions about changing plant use in the past (Pearsall 1983; Popper 1988).

A useful alternative to assessing dominance is ubiquity analysis, the third approach employed by Weber (1991, 1993). This approach has been promoted by Hubbard (1975, 1980) as 'presence analysis', in which taxa are scored on the basis of percentage of the total number of samples in which they occur (also Popper 1988; Pearsall 1989: 212-17). There are different scales at which this approach can be applied, such as comparing contexts within a site or sites with a region. This approach may, however, over-emphasize taxa that only occur in samples as rare elements. For particular questions it may then be useful to compare particular taxa through the use of ratios which might highlight trends in the changing relative quantities of particular taxa of interest (Miller 1988; Pearsall 1989: 197-210). Others have utilized various indices, such as species diversity (Pearsall 1983, 1989: 211; Popper 1988; Lone et al. 1993). In general, there is no one correct way to quantify archaeobotanical data. This argues for the full reporting of raw counts so calculations are open to others. Presentation of reasoning for the choice of a particular quantification method should be provided.

Statistical analyses of archaeobotanical data remain contentious amongst archaeobotanists, especially as to whether the data require or preclude complex statistical approaches. Discriminant and multivariate statistical approaches have been increasingly applied to European archaeobotanical assemblages in recent years (e.g. G. Jones 1984, 1987, 1991, 1992; G. Jones et al. 1995; van der Veen 1992, 1995; also Pearsall 1989: 217-21), and this approach appears to be useful for grouping and separating assemblages on the basis of the presence, absence and co-occurrence of taxa. Such groupings have in some cases been interpreted as representing different stages in crop-processing or differences in arable ecology, due to soil types, irrigation or mixed cropping (G. Jones 1987, 1992; G. Jones and Halstead 1992; G. Jones et al. 1995; van der Veen 1992). While these techniques may be useful for highlighting groupings of samples, it remains necessary to understand the basic differences between these groups, such as in the presence or absence of particular taxa, in order to interpret the meaning of statistical groups. However, given the whole range of uncontrollable taphonomic factors that affect assemblage composition, it has been argued that such statistical approaches may be futile and even misleading (Hubbard and Clapham 1992). As Pearsall (1989: 196) recommends: 'do not use approaches that require more rigor than the data are capable of sustaining'.

In general it is accepted that analysis should begin with simple form of quantification such as relative frequencies, ubiquity or ratios. Hubbard and Clapham (1992) advocate the use of simple quantification methods, such as ubiquity, taxa diversity and indices based on ratios, such as their 'rubbish index' that compares the ratio of crop to non-crop species, or ecological indices such as woodland-non-woodland, wetland-non-wetland, etc. The potential of exploring archaeobotanical data through the use of ratios between

key taxa or groups of taxa has been discussed by Miller (1988) and Pearsall (1989). In South Asian archaeobotany quantified reports are still few and most that are quantified have relied on basic comparisons of relative proportions (e.g. Kajale 1988b; Weber 1991; Lone et al. 1993; Reddy 1994). These can be problematic to interpret, however. Kajale (1988b: 792) suggested that greater quantities and relative frequencies of most crop types recovered from levels of the Early Jorwe phase indicated a 'richer' plant economy than earlier or later phases. Such an assumption, however, is problematic since the difference could be due to changes in taphonomic factors, such as the organization and scheduling of processing (see comments of Ratnagar 1989). Kajale (1988b) is probably right, however, that the marked increase in overall density of plant remains and charred coprolites resulted from some form of intensification.

Lone et al. (1993) attempted to move beyond simple frequency comparisons by also using measures of species diversity and richness in samples. These measures were then tested as to their 'randomness' or 'non-randomness' in order to highlight the taxa which showed chronological patterns. Employing these measures they found relatively little change and it is not clear that such methods were entirely necessary. In addition, they calculated 'standard scores' which downplay absolute counts of taxa but highlight changes, in this case between phases, suggesting a decrease in barley quantities through time with a corresponding increase in rice (Lone et al. 1993: 233). One difficulty with diversity indices, is that there are a range of available methods for calculating 'diversity' not all of which are comparable or necessarily archaeologically meaningful; it is therefore necessary to be clear about the reasoning behind the use of a given index. Unfortunately quantitative approaches in Indian archaeobotany need to be more widely discussed and employed before significant comparisons between sites, regions and periods can be carried out. In the meantime, comparisons will continue to be based on presence/absence and ubiquity assessments.

3.3 RECONSTRUCTING SUBSISTENCE SYSTEMS: SEASONALITY AND RESOURCE CATCHMENT

In the past two decades increasing discussion has been devoted to moving from archaeobotanical evidence to reconstructing systems of agricultural organization, often in conjunction with other sources of evidence. Interest has focused to varying degrees on establishing the seasonality of cultivation activities, the integration of plant-based activities (cultivation and collecting) and animal husbandry, and the extent of the catchment from which sites procured their resources, whether entirely locally (and if so, from how large an area) or whether some form of exchange and movement of resources between sites and regions was in operation. The development of these interests should be seen in the context of a larger shift in archaeological interest towards ecological and economic questions, often associated with the development of processual archaeology, and the increasing interdisciplinary nature of archaeological excavations (see Fuller and Boivin in Vol. IV of this series).

The important contrast between the winter seasonality of crops of Southwest Asian origin and the summer/monsoon seasonality of many other crops of importance in the Indian subcontinent had already been noted by some archaeologists and botanists (e.g. Allchin and Allchin 1968; Fairservis 1971; Hutchinson 1976). More recently, considerations of cropping seasonality in agriculture have been produced by archaeobotanists on the basis of archaeobotanical finds (Costantini and Biasini 1985; Kajale 1988b; Weber 1991, 1997; Saraswat et al. 1994: 321; Reddy 1994; also Thomas 1983b). At Harappa preliminary analysis suggests shift from exclusively winter cultivation to two cropping seasons during the Late Harappan period, c. 2200 BC (Weber 1997; see also Meadow 1989, 1996; Franke-Vogt 1995: 32-4; Fuller and Madella in Vol. II of this series).

The importance of *kharif* (summer) cultivation for the establishment of permanent settlements in monsoonal India (i.e. east of the Indus region) has emerged as an issue of particular interest. Possehl attributed the proliferation of sites in Gujarat in the Late Harappan period at the end of the third millennium BC (1980: 8-9, 54) to the availability of summer cultivated (*kharif*) millets, especially those originating in Africa. The importance of *kharif* millet crops in this region has been confirmed by subsequent systematic archaeobotany (Vishnu-Mittre 1990; Weber 1991; Reddy 1994, 1997; Dhavalikar 1995), although most of these are not African in origin (see Section 5.7.2-3). Possehl (1986, 1997: 93) later suggested that African millets paved the way for agricultural development in west-central India in the second millennium BC. However, growing evidence suggests that indigenous summer millets were first (Weber 1998; Fuller et al. n.d.), and also that indigenous summer pulses were important (see Table 8 and Section 5.1). The evidence from Inamgaon (Kajale 1988b) and other Chalcolithic sites from west-central India, points to two cropping seasons, i.e. a synthesis of the monsoonal cropping based on crops of South Asian and African origin and winter crops originating in Southwest Asia. Understanding the relative contribution of these two seasons, the nature of differences between them in terms of irrigation, tillage and crop rotation all remain issues to explore in future research.

One region of India where attempts have been made to model the subsistence strategy is Maharashtra during the Chalcolithic period. There had already been attempts to estimate populations and the amount of land that would have had to be cultivated to feed them, such as the model of subsistence system of Inamgaon devised by Dhavalikar and Possehl (1974). This model was, however, based on logical deduction from a series of assumptions, rather than trying to develop an understanding of subsistence from an extensive database of bio-archaeological evidence (for an insightful critique of this model and its subsequent incarnations see Ratnagar 1989). Subsequently, once there was a large archaeobotanical data base from Inamgaon and a reconstruction of its subsistence scheduling (Kajale 1988a), Shinde (1987) produced a reconstruction of the Deccan Chalcolithic cultivation system by combing the regional settlement pattern, tillage potential of the soil, based on modern ethnographic analogy, and preserved digging implements, as well as evidence for storage systems and possibly canal irrigation. The latter was perhaps necessary for intensive cultivation of winter crops like wheat, barley, peas and lentils (Kajale 1988a: 308).

Models of the subsistence system of past sites or regions that model the flow of resources between the human community, crops, livestock, and the surrounding environment have been produced for the north-western part of the subcontinent, and as yet few other areas. Working from checklists of find types, including botanical species, Jarrige and Tosi (1981) attempted to reconstruct the spatial areas around the site, whether local or distant, from which plant resources were procured. Thomas (1983a, 1983b) produced a theoretical model of the subsistence system of the Bannu Basin (Northwest Frontier Province, Pakistan) in the third millennium BC in conjunction with excavations at the sites of Tarakai Qila. Initially, Thomas (1983a) focused on the site of Tarakai Qila and the resources available in its local catchment. He then produced models of different possible ways of obtaining the subsistence base, and its relation to the units of production and consumption, subsequently applied by Weber (1991: 113-16) to the Rojdi data. Thomas (1983b) argued for a 'subsistence economy' in which the village was essentially self-sufficient (i.e. the unit of production was the same as the unit of consumption and the exploited territory was local). This interpretation was based in part on assumptions drawn from producer/consumer interpretations of archaeobotanical assemblages (discussed earlier in Section 2.3), since evidence was found for threshing by-products. Thomas then modelled the flows of energy and products in the entire annual cycle of cultivation and herding. A similar model was produced for Rojdi by Weber (1991). This kind of model was taken a step further by Reddy (1994) who attempted to predict which products and by-products from an agro-pastoral economy might be preserved and recovered archaeologically. Non-equilibrium models, which emphasize historical contingencies and dynamic changes, have become increasingly important in ecology, and challenge us to move beyond the straightforward homeostatic systems that have generally been used to model agricultural systems (Thomas 1989; Blumler 1996; Harris 1996b). In general, more work needs to be put into integrating archaeobotanical evidence with both taphonomic models and models of agricultural systems.

4. PROBLEMS AND DEVELOPMENTS IN IDENTIFICATION

More explicit discussion of identification criteria is immediately needed, especially of seeds. While wood identifications from the earliest reports of Chowdhury and Ghosh were thoroughly documented, with anatomical descriptions, drawings and photographs, seed identifications have not always been as completely reported nor as reliable. Although photographs were often published, they often have failed to convey adequate detail for all seed types, and it has been recommended by some archaeobotanists that drawings provide more reliable reproductions of the criteria relied upon in determinations (Goddard and Nesbitt 1997). Misidentifications have been reported in several instances when specialist examination was not yet complete (see comments of Kajale 1989c: 93), such as the rice reported from Harappan Kalibangan (Sarma 1972; Vishnu-Mittre 1974; unfortunately repeated by Conningham 1995: 67), which further examination revealed to be wheat (Vishnu-Mittre and Savithri 1975). Unlike modern botanical data, where

specimens consist of selected pieces of more or less whole plants, selected by the botanist for their information potential, archaeological plant remains are fragments which have survived processes of decay and destruction that have no regard for research questions. Thus systematic characters of plants used by modern taxonomists or agronomic botanists may be of little or no use to the archaeobotanist who is forced to work with whatever plant characteristics are present in the archaeological samples (see Hather 1994d). In order better to recognize certain species, studies of comparative material relevant to what is preserved archaeologically are needed. A few have already appeared in India, such as those by Vishnu-Mittre and Savithri of *Setaria* (1978), *Eleusine indica* and *E. coracana* (Vishnu-Mittre and Savithri 1979b; but see critique of this *Eleusine* study, below), and various forms of wheat (1982; but see reservations below). Subsequently scanning electron microscope (SEM) images were employed to aid identification, especially by revealing epidermal cell patterns when these are preserved (e.g. Korber-Grohne 1981 in Europe; Lone et al. 1993 in India), or wood anatomy (Buth and Bisht 1981). These studies represent the increasing care that was taken with documenting identification procedures from the mid-late 1970s onwards. Nevertheless, there remain some problem areas in archaeobotanical identification which have not received as much attention as they deserve, and will therefore be briefly reviewed here.

Seed measurements often are reported as supporting evidence in identifications (e.g. Vishnu-Mittre 1961; Vishnu-Mittre and Savithri 1982; Kajale 1984, 1988b; Saraswat 1986, 1993). Measurements, and size ratios offer a useful way of comparing both specimens and assemblages. Nevertheless, measurements alone are ambiguous and problematic. As population biology makes clear, contemporary populations include a range of variation in size and form. An individual measured specimen presents an interpretative ambiguity, at best excluding some categories with high probability, as it cannot be determined where the measured individual would fall within the frequency distribution of a past population (Hubbard 1992). Measurements of specimens can only be meaningful when analysed as statistical variation in a population. Fresh seed size and shape may also be affected by various environmental conditions including soil, weather, and disease (Hubbard 1976). More significant still are the effects of charring: seed sizes and shapes change temperatures and durations of heating (Hopf 1955; Hubbard 1976; Boardman and Jones 1990; Lone et al. 1993; Saraswat et al. 1994: 257). Charring ('carbonization') tends to decrease the size of seeds but differentially affects length, width and breadth such that seeds tend towards more spherical forms. This raises particular concerns for the differentiation of some species groups on the basis of length-breadth ratios, such as the Indian *Vigna* pulses (*mung* and *udid*), or kinds of wheat (*Triticum sphaerococcum* as opposed to *T. aestivum* and *T. compactum*). Unfortunately, few experimental carbonization studies have been carried out for most of the crops represented in India, the exception being experiments reported by Lone et al. (1993). However, reported experiments done with other regions in mind can serve as useful guides, since a range of taxa have been charred including, wheat and barley (e.g. Hopf 1955; Jacomet 1987; Boardman and Jones 1990), south-west Asian pulses (Kislev and Rosenzweig 1993), and

a selection of Sudanese 'millets' (Magid 1989). Wilson (1984) has explored the effects of charring on the differential representation of taxa in samples due to the tendency of some species to be destroyed more easily by charring. Despite the important implications of these studies for understanding the formation of archaeobotanical assemblages, they have yet to be satisfactorily taken into account when identification is carried out. For example, Lone et al. (1993) describe and illustrate the seeds of weed species in Kashmir including characters such as colour and minute bristles which will not survive charring and are not of use in archaeobotanical identification (except in rare cases of waterlogging or desiccation). In addition they have not taken into account their own charring experiments in the attribution of archaeobotanical rice to varietal level taxa. Problematic for similar reasons are attempts to separate archaeological rice into *indica* or *japonica* varieties such as have been reported from Chinese material (e.g. Oka 1988: Fig. 6.3; Wenming 1991; Chen and Jiang 1997) and from Navdatoli (Vishnu-Mittre 1961) and Swat (Costantini 1987). Such attributions must be considered highly suspect until more reliable charring experiments and morphometric studies are available (Crawford 1992; Glover and Higham 1996). Fruitful discussion regarding how best to approach identification of the rice remains from sites in south/central China is now developing (e.g. Crawford and Shen 1998; Anping 1998), and similar considerations need to be undertaken amongst archaeobotanists working in India.

Beyond the technicalities of identification, there are also theoretical issues about specific identification. There is a danger of imposing the modern situation in terms of species distribution and taxonomy onto the past. As summarized by Hather (1994d: 3):

The problem for archaeology is that plant remains are often named with reference to, and with influence from, phylogenetic relationships of the *present-day* evolutionary timeplane. The term 'species' should only be used to define a static form of a plant (which itself varies) in a single timeplane (most often the present). If we name an archaeological plant, we are giving a name to a plant of the past, not of the present. If the name is at the species level, and it is the same as the name of an extant plant, we are making a very important statement about the plant's evolution.

While attribution to a modern morphological species is still generally a goal of archaeobotanical research, the presence in the past of extinct varieties or species is likely (Hillman et al. 1996). A few problematic groups of taxa are discussed in the sections that follow.

4.1 WHEAT IDENTIFICATION

One taxon in particular that requires careful archaeobotanical revision is wheat, and a brief review of the difficulties of wheat identification is in order as this has not yet been incorporated into many archaeobotanical studies in South Asia. Table 4 provides a summary of wheat taxonomy, and Figure 1 illustrates general and specific morphological features referred to in this discussion. Systematic considerations of wheat identification in South Asia (e.g. Vishnu-Mittre 1974; Vishnu-Mittre and Savithri 1982; Vishnu-Mittre et al. 1986a; Chowdhury et al. 1977; Lone et al. 1993) must be reconsidered. The re-examination of material from the sites of Harappa, Mohenjo Daro and Chanhu Daro

provides a wealth of measurements of modern and archaeological wheat grain dimensions, especially as expressed in length-width ratios (Vishnu-Mittre and Savithri 1982), but raises two important problems. First, the range of wheat types that are considered is limited and therefore assumes which wheat types may or may not have been present in the Indian subcontinent in prehistory. For example, they include only hexaploid forms of free-threshing types (*Triticum aestivum*, sensu lato). Free-threshing tetraploid wheat, such as the modern *T. durum* Desf. (macaroni wheat or hard wheat) is not even discussed. This is particularly distressing, since *T. durum* constitutes one of most important forms of wheat in parts of India today, notably in Rajasthan, Gujarat, Uttar Pradesh, Madhya Pradesh, Maharashtra and Karnataka (Pal 1966). Furthermore, it is now clear that free-threshing tetraploid wheats played an important role throughout prehistoric Europe and the Near East and probably developed and diffused before hexaploid types (van Zeist 1976; Kislev 1984a, 1984b; Zohary and Hopf 1993: 46; Maier 1996). Second, a comparison of the ratios of different wheat types given by Vishnu-Mittre (1974; Vishnu-Mittre and Savithri 1982; Vishnu-Mittre et al. 1986; Saraswat 1986) with those reported in an extensive compilation of similar measurements from Europe (Jacomet 1987) indicates discrepancies between South Asia and Europe in the metrical characters of the same wheat types. Thus the ratios considered adequate to characterize Indian *T. sphaerococcum* are similar to those which were traditionally used for European *T. compactum*. The *T. sphaerococcum* length:breadth ratio advocated by Vishnu-Mittre and Savithri (1982; also Saraswat 1986) would be considered *T. aestivum* or *T. compactum* in traditional European archaeobotany. Standard measurements of archaeological '*T. sphaerococcum*' in the literature easily fall within the range of the free-threshing types documented at extensively sampled sites where there is no suggestion of sphaerococcoid grains, such as Shortugai in Afghanistan (Willcox 1991) and Inamgaon, Maharashtra (Kajale 1988b). However, a more serious problem with this older work is the now established fact that tetraploid and hexaploid free-threshing wheats cannot be distinguished on the basis of grains at all, but rather that distinctions must rely on careful examination of preserved rachis segments (Kislev 1984a; Miller 1992; Zohary and Hopf 1993; Maier 1996; Hillman et al. 1996; Schlumbaum et al. 1998b). As noted by Maier (1996) there is a wide range in the size and shape of a caryopsis of wheat depending on the position of the grain and the number of other grains developing within a spikelet (Fig. 1A). As amply demonstrated by the study of the wheats from Shortugai, Afghanistan (Willcox 1991), free-threshing wheat can take on a wide range of morphological and metrical variation, and the best approach is to try to summarize the variation in the ancient material without trying to impose modern categories, which are themselves often poorly defined in metrical terms. These realizations have profound implications for our understanding of the history of Indian wheats, especially as the tendency with archaeobotanical material from South Asia has been to identify *T. sphaerococcum* more or less everywhere. This attribution seems more likely a product of the fortuitous effects of charring than an actual historical dominance of short wheat.

The best way to approach identifications of wheat is through the examination of 'chaff,'

TABLE 4. TAXONOMY OF *TRITICUM* (WHEAT) (after Zohary and Hopf 1993)

Biological species	Traditional binomial	Ploidy	Common name (glume status)
<i>T. monococcum</i> L.	<i>T. monococcum</i> L.	2x (A)	einkorn wheat (glume)
	<i>T. boeoticum</i> Boiss. emend. Scheim	2x (A)	wild einkorn (glume)
<i>T. turgidum</i> L.	<i>T. urartu</i> Tuman.	2x (A)	wild einkorn (glume)
	<i>T. dicoccoides</i> (Körn.) Aarons.	4x (AB)	wild emmer (glume)
(sensu lato)	* <i>T. dicoccum</i> Schübl.	4x (AB)	cultivated emmer (glume)
	* <i>T. durum</i> Desf.	4x (AB)	macaroni wheat (naked)
	<i>T. turgidum</i> L.	4x (AB)	rivet wheat (naked)
	<i>T. polonicum</i> L.	4x (AB)	Polish wheat (naked)
	<i>T. carthlicum</i> Nevski	4x (AB)	persian wheat (naked)
	<i>T. araraticum</i> Jakubz.	<i>T. timopheevi</i> Zhuk.	4x (AG)
<i>T. aestivum</i> L. (sensu lato)	<i>T. spelta</i> L.	6x (ABD)	spelt (glume)
	<i>T. macha</i> Dekr. and Men.	6x (ABD)	(glume, compact)
	<i>T. vavilovii</i> Tuman.	6x (ABD)	Vavilov's wheat (glume)
	* <i>T. aestivum</i> (= <i>T. vulgare</i> Host.)	6x (ABD)	bread wheat (naked)
	<i>T. compactum</i> Host.	6x (ABD)	club wheat (naked, compact)
	* <i>T. sphaerococcum</i> Perc.	6x (ABD)	shot wheat (naked, dense)

NOTE: *Wheat types grown in India/Pakistan in recent times (see Pal 1966).

which has almost never been reported nor discussed in South Asian archaeobotany (Fig. 1B-D, with rice and barley shown for comparison). In hulled wheats, the diagnostic element is the spikelet fork in which a rachis segment (or glume forklet) disarticulates cleanly, and it includes a rachis segment with an articulation scar where the next segment would attach), and the basal portions of the glumes on either side of the articulation scar (see Hubbard 1992; Zohary and Hopf 1993; Nesbitt and Samuel 1996). In free-threshing wheat, rachis segments, sometimes preserved in articulated groups or broken apart (not disarticulating), provide the reliable characters for identification (J. Renfrew 1973; Kislev 1984a; Jacomet 1987; Hubbard 1992; Maier 1996; Hillman et al. 1996). Free-threshing rachis segments will be described as viewed on the abaxial surface. Tetraploid free-threshing wheat (*T. durum*) has swollen glume bases, and the sides of the rachis internode below them are generally more or less straight and converging downwards, the internode often has visible venation, like fine striations (Fig. 1D). Hexaploid free-threshing wheats (*T. aestivum* sensu lato) lack the bulging glume bases and the rachis internode is sometimes (but not always) constricted below the glume bases (Fig. 1B-C). Usually a pronounced vein runs parallel to each side of the internode (Fig. 1B). Free-threshing hexaploids vary widely in terms of how long the internodes are and how much they are constricted. It can be difficult to tell dense-eared *T. aestivum* from *T. compactum* (Willcox 1991; Miller 1992; Hillman et al. 1996). The particular characters that might distinguish *T. sphaerococcum* have yet to be pursued rigorously. Another approach to distinguishing wheat to ploidy level that may be employed in some future studies is through the extraction

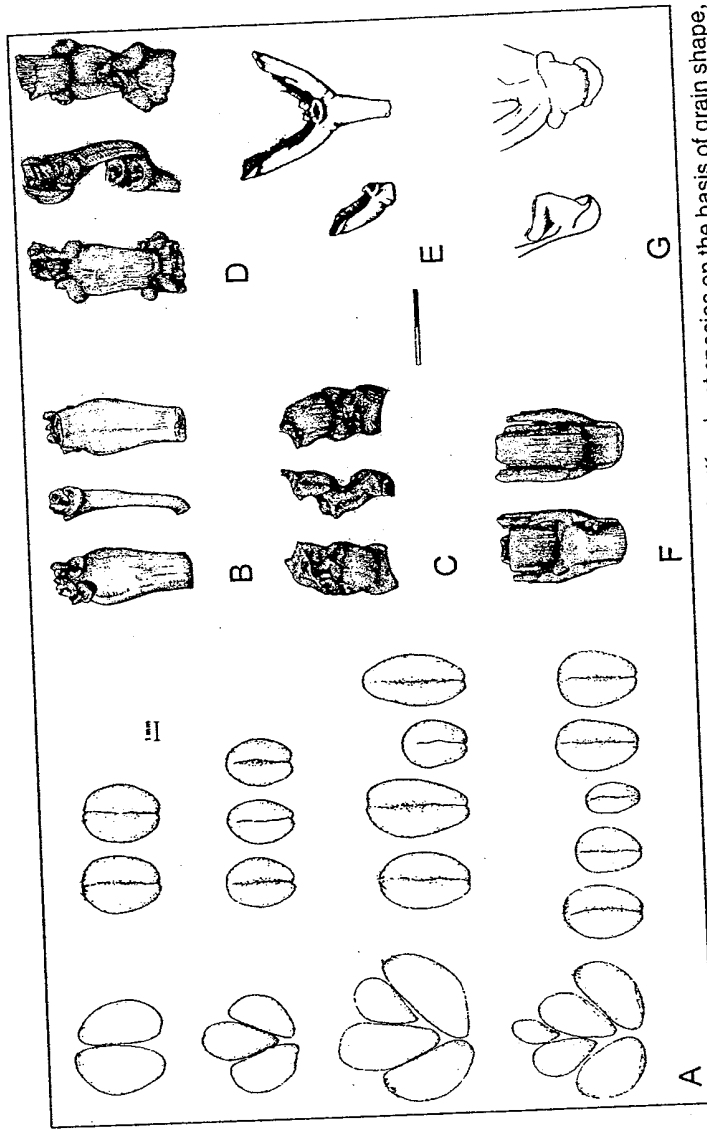


Fig. 1. Illustration showing the problem with attempting to identify wheat species on the basis of grain shape, and useful chaff criteria for identifying the ploidy level of free-threshing wheats, with hulled wheat, barley and rice chaff for comparison. A. Different grain shapes produced by spikelets with 2, 3, 4, or 5 fertilized florets (after Maier 1996). Note small, roundish grains that could be mistaken for *T. sphaerococcum*. B. Archaeological Free-threshing, loose-eared hexaploid wheat rachis segments (after Goddard and Nesbitt 1997). C. Archaeological, free-threshing, dense-eared hexaploid wheat rachis segment (after Goddard and Nesbitt 1997). D. Free-threshing, tetraploid wheat rachis segment (after Goddard and Nesbitt 1997). E. Typical chaff fragments from hulled wheat, glume base on left, complete spikelet fork on right (after Nesbitt and Samuel 1996). F. Archaeological barley rachis segments (after Goddard and Nesbitt 1997). G. Author's sketch of rice glume base.

of ancient DNA (Sallares et al. 1995; Schlumbaum et al. 1998b), poor DNA preservation in most archaeological samples will probably keep this from becoming a routine technique (see Section 6.5).

Accurately distinguishing these wheat varieties is of interest for both botanical and anthropological reasons. First, it is necessary if the different histories of these wheat species and their evolution is to be understood. Second, species level wheat identification could provide some insights into agricultural ecology, since different species have general ecological tendencies. For example, *T. durum* is generally more drought resistant and has greater disease resistance, which has contributed to its importance in much of central India (Percival 1921; Pal 1966; Zohary and Hopf 1993). However, imposing modern ecological preferences onto ancient remains is problematic due to the possibility of extinct varieties with different tolerance in the past (T. Miller 1992). In addition, the hulled and the free-threshing varieties would have required different amounts of processing and may have different potential in terms of storage duration or susceptibility to damage during storage. However, within any of the traditional wheat species there is a wide range of variation, with different varieties possessing different characteristics in terms of agricultural and food traits. Unfortunately, most of this variation will remain invisible from traditional archaeobotanical remains.

4.2 MILLETS HULLED AND DE-HULLED: CASES OF MISTAKEN IDENTITY?

Millet identification remains a particular problem. This is due in part to a failure to recognize the differences between charred and fresh material and insufficient comparative collections of millets and related wild species. The purpose of this section is not to provide a comprehensive guide to millet identification but to draw attention to problematic reports. Some identifications require revisions, others may be right, but most lack sufficient documentation in publication for specialists to judge for themselves. There is need for discussion amongst archaeobotanists, and careful documentation, to establish reliable and replicable criteria for distinguishing millets, and not just those species which are most often cultivated today but a whole range of species which could have been utilized in antiquity. (For some preliminary criteria see Fuller et al. n.d.)

'Millets' include a wide range of small-seeded, edible grasses. Most studies take into account the potential presence of perhaps half a dozen millets, including the three African millets (*Eleusine coracana*, *Pennisetum glaucum*, *Sorghum bicolor*), foxtail millet (*Setaria italica*), two species of *Panicum*, and *Paspalum scrobiculatum* (e.g. Vishnu-Mittre 1971; 1974, Lone et al. 1993). However, there are a number of additional species of 'millet' both cultivated and gathered wild in parts of India today which have rarely been taken into account when studying ancient material (see Table 5). It is possible therefore that some of these species have not been identified simply because we have not been looking for them. A more fundamental oversight, in many studies, including those of Vishnu-Mittre, was a failure to take into account the effects of charring, which usually destroys the husk that surrounds the grain (i.e. the lemma and palea). While finger millet is free-

threshing and easily loses its husk, the other small millets retain theirs and in normal preparation they must be pounded and winnowed to remove these husks. Vishnu-Mittre's (1971: 126) discussion of comparative material of other millets he considered when identifying the Hallur millets, including *Setaria italica*, *Panicum* spp. and *Paspalum scrobiculatum*, indicates that he examined them as hulled seeds. Since he did not take into consideration the form of the dehulled caryopses of these other genera, the attribution to *Eleusine* must have been due to a false process of elimination in which *Eleusine* was the only small, 'free-threshing' millet. Indeed, in cases where its identification criteria are clear, *Setaria* is identified only when it retains its lemma and palea and it raises the possibility that dehusked *Setaria* caryopses have been mis-identified.

Many of the published reports of finger millet need to be reconsidered, as several of them are clearly not *Eleusine*. The published photographs from Hallur (Vishnu-Mittre 1971), although inadequate for identification, are more suggestive of *Setaria* or *Echinochloa*, and a representative of the former genus has been found in quantity in

TABLE 5. 'MILLETS' UTILIZED IN INDIA IN RELATION TO GRASS TAXONOMY

subfamily Chloridoideae: Eragrostideae
^D *Eleusine coracana* (L.) Gaertn., finger millet, ragi (H.)

subfamily Panicoideae: Paniceae
^{w,D} *Brachiaria ramosa* (L.) Stapf. (syn. *Urochloa ramosa* (L.) Nguyen) browntop millet, *pedda-sama*
^{w,D} *Digitaria cruciata* (Ness) A. Camus var. ^D *esculenta* Bor, *raishan* (Khasi)
^{w,D} *Echinochloa colona* (L.) Link ssp. ^D *frumentacea*, sawa millet, *sawank*¹
^w other *Echinochloa* species (known as 'famine foods'): *E. crusgalli*, *E. stagnina*
^D *Panicum mihaceum* L., proso millet
^{w,D} *Panicum sumatrense* Roth. (syn. *P. militare* auct. pl.), little millet, *samai*²
^w other *Panicum* species (known as 'famine foods'):
P. atrosanguineum, *P. hippothrix*, *P. paludosum*, *P. trypheron*, *P. trugidum*
^w *Paspalidium flavidum* ('famine food')
^{w,D} *Paspalum scrobiculatum* L., kodo millet
^D *Pennisetum glaucum* (L.) R. Br. (syn. *P. americanum* Leeke; *P. typhoides* Rich.), *bajra*, pearl millet³
^w *Pennisetum alopecuroides* ('famine food')
^D *Setaria italica* (L.) Beauv., common foxtail millet
^{w,D} *Setaria pumila* (Poir.) Roem and Schult. (syn. *S. glauca* auct. pl.), yellow foxtail millet, *korali*⁴
^w *Setaria verticillata*, bristley foxtail; *Setaria intermedia* Roem and Schult. (syn. *Setaria tomentosa* (Roxbi) Kunth.)
^w *Urochloa* spp. ('Famine food')

subfamily Panicoideae: Andropogoneae
^D *Sorghum bicolor* sorghum, great millet, jowar

NOTE: Species preceded by ^D, are those in which a domesticated form has developed, while those preceded by ^w are only known to be gathered from the wild and therefore likely to have undergone little/no genetic change due to human usage.

SOURCES: Rachie 1975; Vishnu-Mittre 1981b; 1985; Rehm and Espig 1991; De Wet 1992; Mehra 1997. Grass taxonomy follows that of Clayton and Renvoize 1982. For additional discussion of taxonomy and current, correct nomenclature see references in the following notes:

¹ Yabuno 1962; De Wet et al. 1983c; Hilu 1994.

² De Wet et al. 1983a.

³ Clayton and Renvoize 1982: 672; De Wet 1995d.

⁴ Clayton 1979; Prasada Rao et al. 1987.

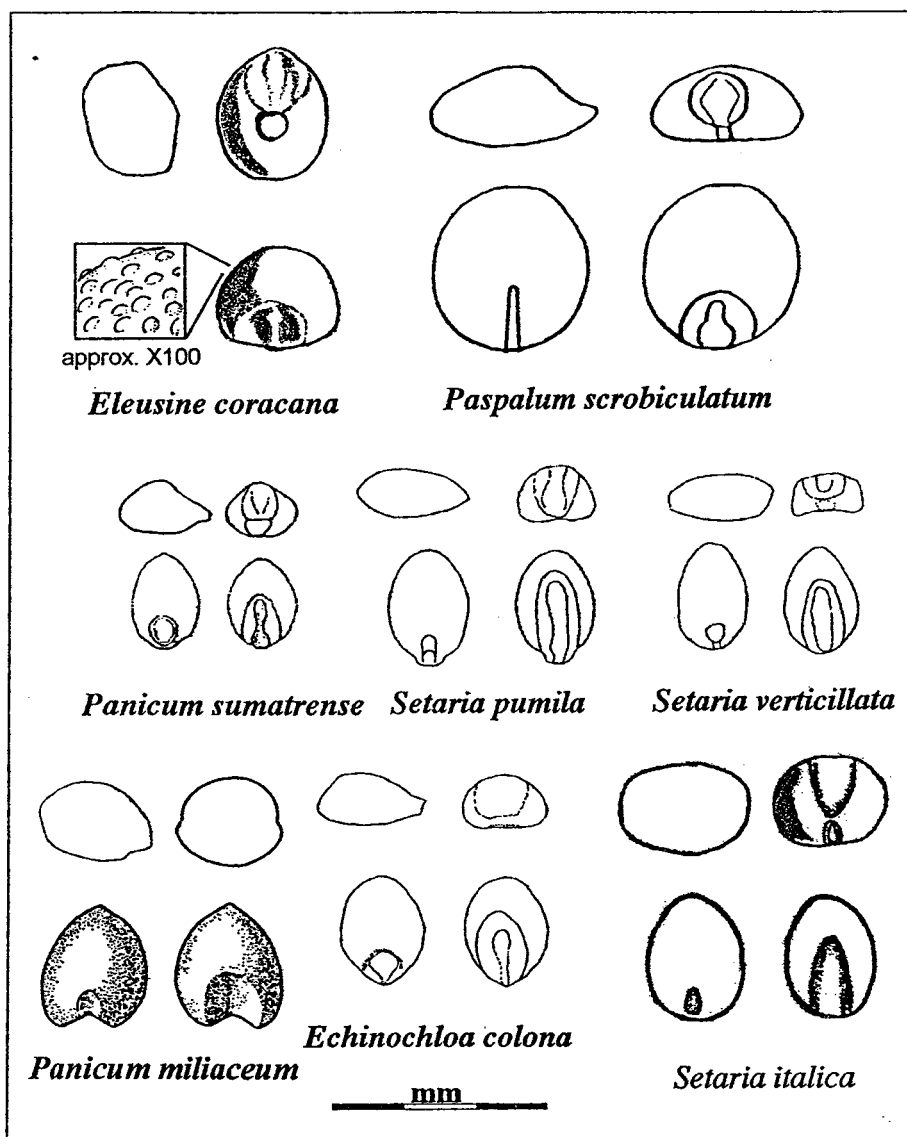


Fig. 2. Schematic drawings of selected small 'millets' showing some of the traits useful for differentiating genera and species. Millets are generally shown in dorsal view (lower right) which shows the size and shape of the embryo/scutellum, ventral view (lower left) which shows the hilum, in longitudinal section (upper left), and 'head on' (apical) looking towards the embryo (upper right). Note that *Eleusine coracana* has a minutely pustulate surface, shown in schematic form in the inset box. Also in *Eleusine* the hilum is visible in the 'head on' view while the ventral surface is featureless or sometimes transversely furrowed.

recent resampling at the site and other contemporary sites in the regions while *Eleusine* has not been found (Fuller *et al.* forthcoming; also, Kajale 1989b, 1998). In addition to claiming the presence of finger millet (which is so often cited), Vishnu-Mittre argued that it co-occurred, within the same groups of spikelets, with a thinner, more oblong form which, he reasoned, must be the related wild species *E. indica*. The Hallur identifications, as well as the claim for indigenous origins of finger millet, were criticized by Hilu *et al.* (1979) as well as Harlan (see Vishnu-Mittre 1977: 575, n.1). Vishnu-Mittre and Savithri (1979b) subsequently revoked the identification of *E. indica*, which is not just more oblong than *E. coracana* but has a rugose rather than pustulate surface (ornamented with small protuberances), although they maintained the identification of *E. coracana* and also identified it at Surkotada, Gujarat (Vishnu-Mittre 1990).

The comparative study of finger millet published by Vishnu-Mittre and Savithri (1979) itself seems unreliable for the same basic reasons as the Hallur identification. In the material from Surkotada, *Setaria* (considered likely to include *S. italica* and *S. verticillata*, Vishnu-Mittre 1990) is identified exclusively on the basis of specimens with intact rugose lemma and palea preserved (see Vishnu-Mittre and Savithri 1978, 1982, pl. 18.4, nos. 1-3; also the case with Daimabad, Vishnu-Mittre *et al.* 1986; and possibly Rojdi, Weber 1991: 89-90), while *Eleusine* is always identified from caryopses (e.g. Vishnu-Mittre and Savithri 1982, pl. 18.4, no. 4). As illustrated, many of these specimens are too ovate (non-globose) and they have very long, deep embryos (a trait of *Setaria* and *Echinochloa*) while those of *Eleusine* are shallow and short (usually about 1/3 of the grain length). On the basis of the published photos, the Surkotada material appears to consist almost entirely of *Setaria*, some of which preserve the lemma/palea while on many others this is missing, probably destroyed during the charring process. The other species recovered from this site compare well with the weed taxa found by Reddy as weeds and crop-processing by-products of millets ethnographically and archaeologically at Babar Kot where *Setaria* was also prominent (Reddy 1994, 1997). Unfortunately, the criteria of Vishnu-Mittre and Savithri seem to be accepted as standard, and the report of finger millet from Hulas seems to have relied on them (Saraswat 1993). The illustrated rugose 'testa' (*ibid.*, pl. II, 12) has sinuous rugae of the sort encountered on *Setaria* lemma/palea rather than the smoothly curved rows of granulae characteristic of an *E. coracana* pericarp.¹ The grains, as Saraswat notes, each have a broad 'hilum' (actually the scutellum or embryo area), 'almost half the length of the grain' (*ibid.*: 6) and it can be noted in the illustration (*ibid.*, pl. II, 10) that this scar comes to an acute end. This embryo is too long relative to grain length to be *Eleusine*, and is more probably *Setaria* seen in dorsal view; in addition, if it were *Eleusine*, viewed from the base, one would expect to see the small circular hilum, which occurs immediately below the scutellum in this genus, rather than on the ventral side (as in *Setaria* and other panicoid grasses).

Unfortunately, given the fact that most of the well-illustrated reports of finger millet/ragi in India appear to be mis-identified, one must be circumspect in relying on any of the other reports which are not accompanied by illustrations and may have accepted the approach of earlier workers. Thus compilations for early evidence of millets in South

Asia, as evidence for trade with Yemen/Africa (e.g. Possehl 1998, 1997), must be considered with caution until identification criteria are clarified. For millets photographs are unsatisfactory for illustrating identifications and drawings are probably best. These drawings need to include at least 3, and preferably 4 views of the caryopsis, including dorsal, lateral, apical, and perhaps ventral. Some exemplars, representing a range of small millets are illustrated in Figure 2.

4.2.1 *Sorghum* Identification: Some Reservations

It is also possible that some of the well-known reports of *Sorghum bicolor*, in South Asia as well as the Arabian peninsula, represent mis-attributions. Several of the prehistoric identifications of *Sorghum* in South Asia have been called into question (Willcox 1992; Rowley-Conwy et al. 1997; Fuller et al. forthcoming). Several of the best known, and most often quoted, examples are based on impressions in pottery, none of which has been convincingly demonstrated to be *Sorghum*. In the case of Ahar in Rajasthan, *Sorghum* was identified on the basis of impressions in pottery which were interspersed with those of rice, rice chaff and straw (Vishnu-Mittre 1969). The attribution to *Sorghum* was largely on the basis of size and the fact that the impressions were round. However, the published photographs (Vishnu-Mittre 1969, pl. XXX) seems to show a long parallel-sided, round-ended embryo on one of the grains, which might suggest *Echinochloa*. Such an attribution may be more logical as *E. colona* and *E. crus-galli* are well known weeds of rice, in particular var. *oryzicola*, a rice mimic which infests paddy cultivation (Hohn et al. 1977; Maun and Barret 1986) and their presence in the pottery along with rice can be understood as the use of rice crop-processing by-products as temper, whereas the inclusion of rice and *Sorghum* in the same ceramics requires assuming two distinct temper sources. The material from Pirak (from the post-Harappan period) was never clearly identified, but reported as simply *Sorghum* sp. with certain reservations expressed (Costantini 1979b).

As noted by Willcox (1992), many archaeologists have overlooked the caution expressed by the original archaeobotanical work and have instead repeatedly cited such reports as well-established scientific fact leading to a general acceptance in the literature. Similar difficulties surround roughly contemporary reports of sorghum from the Arabian peninsula (Rowley-Conwy et al. 1997). The best illustrated example from Yemen is a latex cast made from one of three 'sorghum' seed impressions (Costantini 1990b: pl. 120, c-d). While this is generally large and roundish, and has a small acute projection as sorghum does, there is no evidence of a large embryo/scutellum area, despite this surface being identified as the dorsal surface (ibid.: 193). While this may not have been visible due to the orientation of the impression, without this characteristic feature for the identification of millets and many grasses it is perhaps misleading to attribute this specimen to *Sorghum* as it could come from just about any large, round seeded plant and may not even be a grass. In addition the overall dimensions of these impression are larger than most *Sorghum* grains even of the very large seeded durra varieties (ibid.: 193), which are perhaps unlikely to have been developed at this early date. The best sorghum candidate of any of the

published examples is that from Hili II in Oman, 2330-2250 BC (Costantini 1979a; Cleuziou and Costantini 1980, 1982; Cleuziou 1989). In addition to the impression, a single charred grain of sorghum is also reported from Hili, phase Ib, although it is not illustrated (see Cleuziou 1989). The impression shows part of a spike (infructescence) in which three rachillae are preserved, each ending in an ovoid structure. As these structures lack evident venation, and arise from triangular-shaped rachillae, they do show similarities with *durra* type *Sorghum*. This specimen is accepted by Doggett and Prasada Rao (1995) as an example of the *durra* race, although there remains room for scepticism until additional material is recovered. To accept any of the reputed *Sorghum* impressions from the Arabian or Indian peninsula requires a leap of faith, a situation which can be contrasted to that of the numerous well-documented impressions of wild-type *Sorghum* from Neolithic sites in the Sudan (e.g. Stemler 1990), or the wheat and barley impressions from Arabia and Baluchistan (Costantini 1979a, 1979b, 1983, 1990a, 1990b). Other archaeobotanical research in the Arabian peninsula has failed to turn up *Sorghum* (e.g. Levkovskaya and Filatenko 1992). Unfortunately *Sorghum* in South Asia has often been discussed in terms of crop diffusion through the far-flung trade contacts of the Harappan period (e.g. Possehl 1986, 1997, 1998; Weber 1990, 1991, 1998; Ratnagar 1994; Meadow 1996; Doggett and Prasada Rao 1995), although there is little undisputed evidence to support diffusion either during this period or by this route (see Section 5.7.2, also Fuller and Madella in Vol. IV of this series).

4.3 TROUBLESOME PULSES: THE *VIGNA* SPP.

After cereals, pulses (legumes) are the most common archaeobotanical find in South Asia (Weber 1992), and arguably the next most important category of crop in agricultural terms. When well preserved, identification is quite straightforward, relying on overall shape and placement, size and shape of the hilum. On split legumes, the internal surface of the cotyledon often preserves a scar where the embryo (plumules) had been. The size, shape and position of the embryo can also be distinctive. Most pulse identification in South Asia is excellent, and what little confusion has surfaced from time to time is largely nomenclatural (for current taxonomy and nomenclature see Section 5.3, footnotes and Tables 6-9; for a review of identification criteria for tropical pulses encountered in Indian archaeobotany, see Fuller et al., n.d.; for pulses of South-West Asian origin see Hopf 1986; Zohary and Hopf 1993).

One genus which has presented some difficulties are pulses in the genus *Vigna* (many formerly considered *Phaseolus*). Green Gram/Mung (*V. radiata*) and Black Gram/Urd (*V. mungo*) share a large number of characters in common and the size and general shape of their seeds overlap. No charring experiments with distinguishing morphometric characters have been presented to validate claims to distinguish them in charred material on the basis of size and shape. Nevertheless, if the hilum is preserved, the distinction between *V. radiata* and *V. mungo* is easily made since Black Gram and its wild progenitor

(*V. mungo*) have a raised hilum with an encircling lip, while in *V. radiata* there is no such lip and the hilum is more or less flush with the seed coat surface (Arora et al. 1973; Lukoki et al. 1980). *V. aconitifolia*, the closely related moth bean, can be distinguished by its minute hilum which lies in a slight depression. In addition, these species have distinctive epidermal cell forms on their testas (Chandel et al. 1984). *V. radiata* has rows of very long, thin rectangular cells, whereas those in *V. mungo* are shorter, wider and more ovate. These patterns are readily observable on fresh material at magnifications of 50x or more. *V. aconitifolia* appears to have a much glossier testa and the cells appear to be considerably smaller (author's observation). Other distinctions, on the basis of proportions are probabilistic only. On split cotyledons, the embryo in *V. radiata* is generally larger averaging approximately two-thirds the total cotyledon length, whereas in *V. mungo* it tends to be closer to half the cotyledon length; in *V. aconitifolia* it is usually less than half. While most specific level attributions are likely to be correct there is need for more rigour in presenting methods for distinguishing *V. radiata* and *V. Mungo*.

Another species in this genus which has created some confusion is cowpea, *Vigna unguiculata*. This species has so far only been reported from two sites, Hulas (Saraswat 1993) and Daimabad (Vishnu-Mittre et al. 1986)². In the case of Daimabad it is reported as *Vigna sinensis*, a synonym for *V. unguiculata* cv. *biflora* (Westphal 1974; Smartt 1990). Vishnu-Mittre et al. (1986) also tentatively identify a group of other pulses as *Phaseolus* spp., referring to *P. lunatus* and *P. vulgaris*, bean species of New World origin (Debouck and Smartt 1995); these identifications, indicated as uncertain, are undoubtedly mistaken. The photographs show a range of forms which fit well within the variation covered by the several cultivated varieties of *Vigna unguiculata* (see, for example, plates in Westphal 1974).

4.4 A NOTE ON CASTOR

Another mis-identification appears to be the reported *Ricinus communis* from Ter (Vishnu-Mittre et al. 1971: pl. 1.6; Vishnu-Mittre 1977: pl. 5). This identification can be evaluated on the basis of the published photographs which appear to be quite clear. While the seed appears to be elliptic in shape, as is the case in *Ricinus*, the two most distinctive traits of castor seeds appear absent on the illustrated specimen nor are they mentioned in the description (compare, for example, published drawings of castor seeds in general textbooks, e.g. Pandey 1995: 233; Hickey and King 1991: 271) *Ricinus* has a distinctive longitudinal furrow along the length of the seed and a carbuncle at one end (a squarish protuberance). Vishnu-Mittre's illustrated specimen instead shows a trait which suggests a very different identification: the concentric and nearly complete, light-coloured ring. Such rings are characteristic of seeds in some groups of leguminous trees/shrubs (especially of the Mimoseae or Acaciae), such as *Prosopis* or *Acacia*. Even if the archaeological specimens were *Ricinus*, they were so misleadingly represented in the photographs, and incompletely described in the text, as to call their identification into serious doubt.

5. PLANT DOMESTICATION AND ORIGINS: BOTANICAL AND ARCHAEOBOTANICAL CONTRIBUTIONS

Among the questions most often asked of archaeobotanical remains are when and where various crops were domesticated and how they spread. Evidence for the origins of domesticated crops comes largely from the study of modern species, especially through the establishment of genetic relationships between domesticated and wild taxa (Harlan and Zohary 1966; Zohary 1989, 1996; Zohary and Hopf 1993; Harlan 1986, 1992, 1995a; Ladazinsky 1989; Smartt and Simmonds 1995; and see Tables 6-9). The general regions in which these wild progenitors occur today provide a useful guide to regions in which they are likely to have occurred in the past. All regions have not, however, been equally well-documented, with South-West Asia providing the most reliable evidence at present. The first systematic attempts to uncover the geographical origins of crops was the work of Alphonse De Candolle (1886), who drew upon linguistic evidence in addition to the botany. While some of his conclusions have stood the test of time, many others have been disproven by work during the past century, especially through plant breeding and genetic studies. During the first half of this century, notably the work by Vavilov (1922 [1950]), studies focused on locating areas of the highest diversity within a crop as regions of origin, although this approach has been superseded by better techniques for assessing the relationships between plants. Ideally, phylogenetic (evolutionary descent) relationships can be established between crops and wild populations; the geographical distribution of these wild populations, in turn, can be used as a base for inferring the *general* ancient distribution of these wild progenitors, and hence crop origin. Vavilov developed the concept of centres of origin, regions in which suites of crop species were domesticated, perhaps at about the same time, and from which they spread to other parts of the world. While Vavilov's studies provided an important baseline from which subsequent research could grow and encouraged the use of modern botanical data for addressing questions of crop histories, his work has been superseded. It is therefore unfortunate that his proclamations about regions of origin are still frequently cited despite more recent research (for example, *Cajanus* and *Lablax* are often mis-attributed in terms of their continent of origin). As additional botanical data has accrued many of Vavilov's centres have been discarded and it has been realized that in some parts of the world, such as sub-Saharan Africa, domestications were more widely dispersed; these latter sub-continental areas have been called 'non-centres' (Harlan 1971, 1986, 1995a). Nevertheless, some groups of crops with a common region of origin can be inferred from the archaeobotanical evidence to have diffused as a suite, such as the cereals and pulses of southwest Asian origin.

5.1 *South-West Asian Crops*

The crops which have been most extensively studied are cereals of South-West Asian origin, wheat and barley, followed by the pulses from the same region (selected species are given in Table 6). These crops well illustrate the potential of modern botanical evi-

dence as well as debates about its interpretation. Although from the perspective of the Indian subcontinent these species are well established as having originated to the west, the more precise location of their domestications is controversial. Wild stands of einkorn wheat, emmer wheat and barley persist in parts of the 'fertile crescent' although the modern distributions must be considered with reservations because of environmental change, due to both climatic factors and human impact. Through an understanding of environments in which the wild relatives of crops occur today, and by taking into account evidence for vegetational changes in the past, it is possible to model the approximate areas in which crop progenitors may have occurred at the time of domestication (for a reconstruction of pre- and proto-agricultural South-West Asia see Hillman 1996). More detailed genetic screening can help to eliminate some wild populations from progenitor status (Zohary 1989, 1996; Ladizisky 1989). In addition, the genetics of the crops can suggest the minimum number of domestications necessary to account for different genetic groups.

For many of the staple crops, one or very few domestications seem to be indicated, notably for the South-West Asian pulses, emmer wheat, einkorn wheat and barley (Zohary and Hopf 1993; Zohary 1996). Recently, genetic analysis of modern populations of einkorn wheat (*Triticum monococcum*) has suggested a single domestication event from a restricted genetic population, identified with a limited region of south-east Turkey today (Heun et al. 1998; Nesbitt 1998), although controversy continues as to how reliable modern populations are as guides to locating the ancient population from which einkorn was domesticated (Jones et al. 1997; Hole 1998; Nesbitt and Samuel 1998; Nesbitt 1998). On the other hand, recent work on cultivated emmer races suggests the presence of two deep genetic lineages, presumably representing two domestications or domestication from a genetically heterogenous population (Allaby et al. forthcoming); this evidence might challenge the traditional evidence of plant breeding that argued for domestication 'only once, or at most a few times' (Zohary 1996: 155).

Barley also could have been domesticated twice. Evidence for barley indicates two different genes governing the non-shattering rachis (the key domestication trait of cereals) which argues also for at least two domestications of this species (Zohary and Hopf 1993; Zohary 1996; cf. Ladizinsky 1998), although these have yet to be explored through phylogenetic study of genetic data. The restricted genetic diversity of the crop compared to the wider diversity in wild populations of the western fertile crescent (e.g. Israel), coupled with early archaeobotanical finds from the region is usually taken to indicate domestication(s) there in the Early Holocene (Helbaek 1969; Bar-Yosef and Meadow 1995; Harlan 1995; Ladizinsky 1998). Although the distribution of wild barley currently extends in patches eastwards to Afghanistan and Pakistan (Harlan and Zohary 1966), there is no reason at present to believe that barley was domesticated beyond of the 'fertile crescent' given the chronological priority of agricultural sites in the core South-West Asian area (Bar-Yosef and Meadow 1995; Nesbitt and Samuel 1996). Despite the excitement expressed by some with regard to the 'wild' barley impressions identified in early levels at Mehrgarh (Costantini 1983; Costantini and Biasini 1985; Chakrabarti 1988;

TABLE 6. CROPS OF PROBABLE SOUTH-WEST ASIAN ORIGIN, BOTANICAL AND ARCHAEOBOTANICAL SUMMARY

Crop	Vernacular: English, Hindi, others	Frequent synonyms	Region of origin (References)	Early finds, region of origin	Early finds, South Asia
<i>T. diococcum</i> Schubl. (4n)	emmer, durum, gehu	included in <i>Triticum</i> <i>turgidum</i> L. sensu lato (hulled)	South-West Asia: Fertile Crescent (DPOW)	Asikli Hoyuk, Can Hasan III (Turkey), 7th M. BC; Cafer Hoyuk pre-Pottery Neolithic B (Nesbitt and Samuel 1996)	Melgarh (?), 7th M. BC (Costantini 1983); Rohira, 2300-1700 BC (Saraswat 1986); Kalibangan (?), 2600-2000 BC (cf. Vishnu-Mittre and Savithri 1975)
<i>T. durum</i> Desf. (4n)		included in <i>Triticum</i> <i>turgidum</i> L. sensu lato (naked)		Can Hasan III (Turkey), 7th M. BC; Tell Aswad (Syria)	not yet reported/presumably represented in many reports of <i>T. aestivum</i> (see Sections 4.1. 5.7.1)
<i>Triticum aestivum</i> L. sensu lato (6n)	Bread Wheat, gehu	included <i>T.</i> <i>compactum</i> Host.; syn. <i>T. vulgare</i> Host.; <i>T. sativum</i> Lam.	South-West Asia: West Fertile Crescent	Asikli Hoyuk, Can Hasan III (Turkey), 7th M. BC; Cafer Hoyuk pre-Pottery Neolithic B (Nesbitt and Samuel 1996)	reports probably include <i>T. durum</i> : Melgarh, Baluchistan, 7th M. BC (Costantini 1983); widespread Harappan era sites, 2500-2000 BC (Vishnu-Mittre and Savithri 1982; Weber 1997); after c. 2000 BC in Ganga Basin and Maharashtra
<i>T. aestivum</i> L. subsp. <i>sphaerococcum</i> Perc. (6n)	Indian Shot Wheat, gehu	<i>T. sphaerococcum</i> Perc.	Baluchistan/NW India ?		? identification criteria unclear (see discussion, Section 4.1)
<i>Hordeum vulgare</i> L.	Barley, Yava, Sattu		South-West Asia: West Fertile Crescent and ? second center (DPOW)	8th M. BC; Jericho (Palestinian Authority), Tell Aswad, Abu Hureyra (Syria); 7th M. BC; Numerous sites from Iran to Turkey (DPOW)	Melgarh, Baluchistan, 7th M. BC (Costantini 1983); widespread Harappan era sites, 2500-2000 BC (Vishnu-Mittre and Savithri 1982; Weber 1997); after c. 2000 BC in the Ganga Basin and Maharashtra

<i>Lens culinaris</i> L.	Lentil, Masur	South-West Asia (DPOW)	8th M. bc; Jericho (Palestinian Authority), Tell Aswad, Abu Hureyra (Syria); 7th M. bc; Numerous sites from Iran to Turkey (DPOW)	Harappa, 2500-2000 bc; Kalibangan, 3rd M. bc (Vishnu-Mittre and Savithri 1982; Weber 1997); Rohira, 2300-2000 bc (Saraswat 1986); Burzahom, Kashmir, 2400 bc-1700 bc (Lone et al. 1993); Babar Kot, Gujarat; 2000-1700 bc (Reddy 1994); Maharashtra from c. 2000 bc
<i>Pisum sativum</i> L.	Peas, Mattar	South-West Asia (DPOW)	8th M. bc; Jericho (Palestinian Authority), Tell Aswad, Abu Hureyra (Syria); 7th M. bc; Numerous sites from Iran to Turkey (DPOW)	Harappa 2500-2000 bc (Weber 1997); Burzahom, Kashmir, 2400-1700 bc (Lone et al. 1993); Balathal, Rajasthan, 2400-1800 bc (Kajale 1996a)
<i>Cicer arietinum</i> L.	Chickpea, Bengal Gram, Chana, kadalai (Tamil)	South-West Asia: North Fertile Crescent (DPOW)	8th M. bc; Jericho (Palestinian Authority), Abu Hureyra (Syria); 7th M. bc; Ramad (Syria), Ain Ghazal (Jordan) (DPOW)	Harappan Civilization: Kalibangan, 3rd M. bc, Harappa, 2500-2000 bc (Vishnu-Mittre, Savithri 1982; Weber 1997); after c. 2000 bc in Ganga Basin and Maharashtra
<i>Lathyrus sativus</i> L.	Grass pea, Khesari	South-West Asia (DPOW)	PPNB Gritille (Turkey); 5-6.; sites in Greece and Bulgaria (DPOW)	Harappa, 2500-2000 bc; Babar Kot, 2200-2000 bc; Rojdi (Weber 1991), Ganga Valley sites and Maharashtra, 2000-1600 bc (Kajale 1991; Saraswat 1992)
<i>Trigonella foenum-graecum</i> L.	Fenugreek, methi	South-West Asia/East Mediterranean (DPOW)	Tell Halaf, Iraq, 4000 bc EBA Lachish, Israel (DPOW)	Rohira, 2300-1900 bc (Saraswat 1986)
<i>Linum usitatissimum</i> L.	Flax, Alsi	South-West Asia (DPOW)	8th M. bc; Jericho (Israel), Tell Aswad (Syria); 7th M. bc; Ramad (Syria), Ain Ghazal (Jordan) (DPOW)	Rojdi C (seeds), 2000-1700 bc (Weber 1991); Pirak (seeds) 1950-1550 bc (Costantini 1979); Navda Toli I-II (seeds), Maharashtra, c. 2000-1600 bc (Vishnu-Mittre 1961); Chandoli (thread) 1500-1200 bc (Gulati 1965) (see Janaway and Comingham 1995)

ABBREVIATIONS: DPOW = Domestication of Plants in the Old World, 2nd edn. (Zohary and Hopf 1993).

Saraswat 1992; R. Singh 1990), caution is warranted, as these may only indicate the spread of wild-type barley as weeds of the crop. In general, crops which originated in South-West Asia, now generally placed more specifically in the western fertile crescent (Israel, Syria, South-East Turkey), spread eastwards as part of an agricultural package which included some livestock, goats and probably sheep, to reach Baluchistan by the end of the eighth millennium BC, although this geographical spread is still relatively poorly documented archaeologically and cannot yet be clearly related to either diffusion or migration, although the latter is currently favoured (Bar-Yosef and Meadow 1995).

By comparison to South-West Asian agriculture, the crops (as well as livestock) with origins in other geographical regions are less well understood both botanically and archaeologically, although there is an increasing body of evidence awaiting synthesis. An attempt to synthesize botanical and archaeological evidence, for major cereals and pulses as well as some oil and fibre crops, is given here. It should be noted that no attempt is made at this time to deal with the plethora of other crop types, including fruits, vegetables and tubers. This is because cereals and pulses are best represented archaeobotanically at present. By incorporating recent, or sometimes obscure data, the claims made here differ from what is current in most of the archaeological literature of South Asia and in some cases from standard reference works of agricultural botany. This summary provides a set of working hypotheses to explore in genetic, biogeographic and archaeobotanical research.

5.2 African Crops in South Asia: Millets and Pulses

A number of crops are established as originating somewhere in Africa (Table 7), but it would be wrong to consider these crops as a package in the way that seems plausible for the South-West Asian crops. Most often discussed have been the three major savanna millets, *Sorghum*, *Pennisetum*, and *Eleusine*. Despite some earlier claims for an Indian origin of *ragi*/finger millet (*Eleusine coracana*, cf. De Candolle 1886; Vavilov 1992 [1950]; Porteres 1976; Vishnu-Mittre 1971; Vishnu-Mittre et al. 1984), the discovery of hybridizing wild tetraploids in the East African highlands provided strong evidence for an African origin, now supported by several genetic studies (Mehra 1962, 1963; Phillips 1972; Hilu and De Wet 1976; Hilu and Johnson 1992; Werth et al. 1994; Hilu 1995; De Wet 1995b). This also indicates that this crop's origins took place in an environment other than the lowland savannas where it is well established today in both India and Africa. Genetic data indicates highly restricted variation in the crop by comparison to its wild progenitor and other wild species; this suggests a single (or very few) domestication (Hilu and Johnson 1992; Werth et al. 1994; Hilu 1995). The racial differentiation of *Eleusine* within India suggests that it was first introduced to the plains of the peninsula and subsequently spread to the northern and north-western part of the subcontinent (Hilu and De Wet 1976; Hilu 1995). Additional suggestive evidence for the region from which finger millet originated comes from linguistics: the root **dègi* in a number of Bantu languages from southern Tanzania and northern Malawi may be the source for *ragi* and