The archaeobotany of Indian pulses: identification, processing and evidence for cultivation

Dorian Q Fuller and Emma L. Harvey

Pulses are a significant component of traditional subsistence in South Asia. Reliable identification criteria for identifying these from archaeological seed remains are reviewed. The botanical evidence relating to the wild progenitors and their distribution, especially of Indian natives (*Macrotyloma uniflorum*, *Vigna radiata*, *Vigna mungo)* is summarised, including new evidence from primary botanical research. The problem of seed size increase in pulses is reviewed through a focused study on *Vigna* spp., in which it is shown that seed enlargement is delayed by 1–2,000 years after initial cultivation. The taphonomy of archaeological pulses is considered in the context of crop-processing of pulses, in which an important distinction can be drawn between free-threshing and pod-threshing types. The total archaeobotanical record for pulses in South Asia (India and Pakistan) is summarised and key regional differences are highlighted.

Keywords: legumes, domestication, Neolithic, agriculture, crop processing

Introduction

Pulses represent important crops in most agricultural systems, and legumes have been domesticated for their seeds in several centres of origin. In traditional Indian subsistence, pulses are particularly important, providing a primary source of protein for vegetarian castes as well as for poorer classes without regular access to meat (Kachroo and Arif 1970; Smartt 1990). The role of pulses in double-cropping systems and crop rotations is also well known for helping to maintain or increase soil nitrates. After the large-seeded cereals (wheat, barley, rice), pulses are the most commonly recovered charred plant remains in South Asian archaeobotany (Kajale 1991; Weber 1992; Saraswat 1992; Fuller 2002). Pulses recovered in Indian archaeology include species from the Near Eastern 'founder crops' (*sensu* Zohary 1996; 1999), as well as species native to Africa and to South Asia (Table 1).

In this paper the available archaeobotanical evidence for pulses in South Asia is assessed. Pulses have been reported from 90 sites in South Asia, across a wide geographical area (Fig. 1). Criteria for the identification of pulse species in South Asia are outlined, as a review of the literature suggested that there has been some inconsistency between reports (Fuller 2002, 282–3). Problems and prospects for inferring domestication are discussed with reference to the example of mungbean (*Vigna radiata*). In order to interpret finds of pulses, possible routes to archaeological preservation need to be considered, and therefore a provisional model of alternative pulse crop-processing models is outlined. Then in the light of this background, the available archaeobotanical evidence for pulses in South Asia is reviewed and discussed (based on the sites reviewed in Fuller 2002, with supplemental references). A distinction can be drawn between regions in which sites yield abundant archaeological evidence for pulses and those where pulse finds are relatively rare and some possible explanations are proposed.

Identification criteria for South Asian pulses

The focus of this section will be major agronomic pulses in India that originated in the Old World tropics. Although these taxa have been reported in Indian archaeobotany in the past, detailed

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consideration of identification criteria has not always been presented and illustrated, and there have been some possible mis-identifications in the literature. Several pulses of South-west Asian origins are also reported from South Asian sites, but identification of these is likely to be more straightforward as they have relatively few congeric relatives in South Asia. The present identification criteria are based on modern comparative material (Table 2) and illustrated with reference to archaeological examples drawn from Neolithic sites from South India (the states of Karnataka and Andhra Pradesh) and North India (Orissa and Uttar Pradesh). Tables of measurements are provided for modern populations. Metrical traits of *Vigna radiata* and *V. mungo* are discussed in more detail, below. Anatomical terms and standard measurements are indicated in Fig. 2. The taxonomy of pulses used here follows Smartt (1990).

Identification criteria are suggested which are normally preserved in archaeological material. As the most common form of archaeological preservation, charring, must be understood in terms of its effects on potential identification of pulses. Nevertheless, there have been relatively few experiments on the effects of charring on pulses. Most published charring experiments have been restricted to the major cereals, wheat and barley (e.g. Hopf 1955; Renfrew 1973; Boardman and Jones 1990; Viklund 1998), and Near-eastern/European legumes, such as broad bean (*Vicia faba*), pea (*Pisum sativum*), and lentils (*Lens culinaris*) (Kislev and Rosenweig 1991). The few reported figures for pulses suggest similar extents of shrinkage in which the length is shortened by 10–20% or perhaps somewhat more but the width is less affected, generally closer to 10% (Kislev and Rosenwieg 1991; Lone *et al.* 1993; Braadbharrt *et al.* 2004). These experiments suggest that good analogues for archaeological specimens can be achieved by experimental charring in the 200–300°C range. Recent open fire experiments have shown that open fires may reach much higher temperatures and still preserve pulses (Jupe 2003). Another important experimental result is evidence that destruction of the seed coat is a threshold condition after which shrinkage rates are greatly increased in pulses. For this reason specimens with intact seed coats should to be considered metrically apart from the more common archaeological pulses that lack their testa.

The size, shape, and placement of the hilum is usually quite characteristic but less often preserved, so emphasis has been placed on overall shape, and the shape and placement of the plumule on spilt cotyledons. Most of these species can be readily identified on the basis of these morphological features and only in the case of certain *Vigna* spp. has it been found useful to supplement these with statistical considerations and anatomical features studied with the aid of a scanning electron microscope (SEM). As will be seen, the tropical pulses of the tribe Phaseolae generally have large lateral plumules. Members of this group can be readily separated from those of South-west Asian origin, of the tribe Vicieae (Fig. 3), which mostly have small lateral plumules with long radicles that curl around the edge of the cotyledon, and the otherwise distinctive chickpea (*Cicer arietinum*) of the tribe Cicereae.

No clear way exists for distinguishing wild from domesticated morphological forms in the pulse taxa identified, although cultivation has selected for important genetic changes in pulses, including loss of natural pod dehiscence and loss of germination inhibition mechanisms (Zohary and Hopf 1973; 2000). Unfortunately these traits are not readily

Table 1 Pulses of importance in prehistoric South Asia, considered in this paper, and their region of origin

Latin name	English name	Hindi name	Probable region of origin
Cajanus cajan	Pigeonpea, red gram	Arhar, tuvar	India: Orissa, Northern Andhra, Chattisgarh
Cicer arietinum	Chickpea, Bengal gram	Chana	South-west Asia, Levant
Lablab purpureus	Hyacinth bean, bonavist bean	Sem	East Africa
Lathyrus sativus	Grasspea	Khesari	South-west Asia, Levant
Lens culinaris	Lentil	Masur	South-west Asia, Levant
Macrotyloma uniflorum	Horsegram	Kulthi	India: savannahs; peninsula(?)
Pisum sativum	Pea	Matter	South-west Asia, Levant
Vigna aconitifolia	Moth bean	Moth	India: forest-savannah margin
Vigna angularis	Adzuki bean		East Asia, Japan
Vigna mungo	Urd, black gram	Urd	India: forest-savannah margin, including inner Western Ghats(?)
Vigna radiata	Mung, green gram	Mung	India: forest-savannah margin, including inner Western Ghats(?)
Vigna umbellata	Rice bean		South-east Asia
Vigna unguiculata	Cowpea	Chowli, lobia	West Africa, Ghana

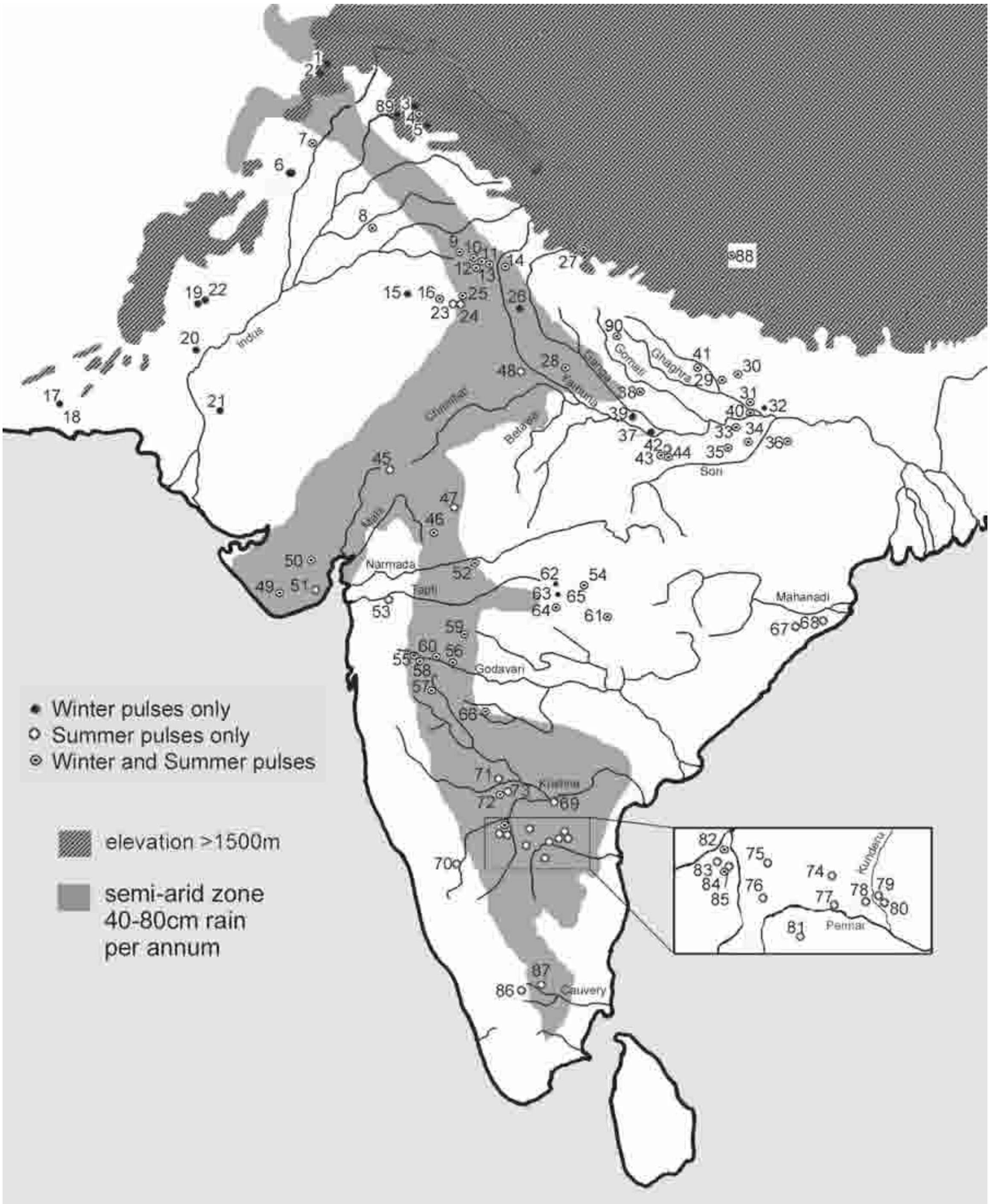

Figure 1 Map of South Asian sites with archaeobotanical evidence for pulses, site numbered: 1. Bir-Kot-Ghwandai, 2. Loebanhr, 3. Burzahom, 4. Semthan, 5. Gufkral, 6. Tarakai Qila, 7. Hund, 8. Harappa, 9. Rohira, 10. Sanghol, 11. Daulatpur, 12. Balu, 13. Mahorana, 14. Hulas, 15. Kalibangan, 16. Kunal, 17. Miri Qalat, 19. Nausharo, 20. Mohenjodaro, 21. Chanudaro, 22. Pirak, 23. Burthana Tigrana, 24. Mangali Ludawala, 25. Mitathal, 26. Lal Qila, 27. Ufalda, 28. Atranjikhera, 29. Imidh-Kurd, 30. Narhan, 31. Manjhi, 32. Chirand, 33. Malhar, 34. Senuwar, 35. Tokwa, 36. Taradih, 37. Kausambi, 38. Hulaskhera, 39. Radhan, 40. Khairadih, 41. Charda, 42. Chopani-Mando, 43. Mahagara, 44. Koldihwa, 45. Balathal, 46. Dangwada, 47. Kayatha, 48. Noh, 49. Rojdi, 50. Babar Kot, 51. Oriyo Timbo, 52. Navdatoli, 53. Kaothe, 54. Naikund, 55. Daimabad, 56. Apegaon, 57. Inamgaon, 58. Nevasa, 59. Bhokardan, 60. Paithan, 61. Adam, 62. Bhatkuli, 63. Kaundinyapura, 64. Tuljapur Garhi, 65. Bhagimohari, 66. Terr, 67. Gopalpur, 68. Golabai Sassan, 69. Ramapuram, 69. Veerapuram, 70. Hallur, 71. Budihal, 72. Piklihal, 73. Watgal, 74. Sanyasula Gavi, 75. Hatibellagalu, 77. Hanumantaraopeta, 78. Injedu , 79. Rupanagudi, 80. Peedamudiyam, 82. Tekkalakota, 83. Kurugodu, 84. Sangankallu, 85. Hiregudda, 86. Perur, 87. Kodumanal, 88. Mebrak Cave, 89. Kanishpur, 90. Saunphari. For data sources see Table 4

Table 2 Metrical traits of seeds in modern populations of pulses

	Length average	Length range	Width average	Width range	Thickness average	Thickness range	Hilum length average	Hilum range
Macrotyloma uniflorum								
PI 427081 01	5·63	4·84 – 6·92	3·75	2·97 – 4·21	2·15	1·57 – 2·75	–	–
PI 364789 01	5·08	4·39 – 5·90	3·48	2·50 – 4·10	1·96	1·40 – 2·35	–	–
PI 196290 01	5·88	5·15 – 6·75	4·27	3·63 – 5·21	1·93	1·35 – 2·34	–	–
Overall ranges for populations		**4·39 – 6·92**		**2·50 – 5·21**		**1·35 – 2·75**	–	–
Lablab purpureus								
PI 164302 02	11·56	10·00 – 12·19	7·92	7·46 – 8·32	5·16	4·98 – 5·55	–	–
PI 542609 01	10·90	9·90 – 11·86	7·44	6·26 – 8·15	4·87	3·85 – 5·65	–	–
PI 364257 01	9·94	9·00 – 11·20	7·30	6·50 – 8·34	5·76	4·71 – 6·60	–	–
PI 219696 01	10·17	8·57 – 11·04	7·87	6·85 – 8·91	5·90	5·04 – 6·45	–	–
PI 509114 01	12·32	11·15 – 13·22	8·24	7·51 – 8·90	5·62	4·65 – 6·02	–	–
PI 212998 01	9·53	8·18 – 10·76	6·99	6·23 – 7·91	5·67	4·95 – 6·46	–	–
PI 764772 01	10·65	9·26 – 11·52	7·08	5·56 – 7·78	4·86	3·62 – 5·61	–	–
PI 288466 01	9·97	8·91 – 11·60	6·93	5·64 – 7·50	4·76	3·70 – 5·20	–	–
PI 338341 01	8·46	7·50 – 9·57	6·25	5·32 – 9·95	3·97	3·07 – 4·58	–	–
PI 195851 01	11·37	10·16 – 12·23	7·38	6·53 – 8·03	4·91	4·38 – 5·76	–	–
PI 347629 01	11·01	10·06 – 11·87	7·58	6·95 – 8·26	4·79	3·35 – 5·89	–	–
PI 288467 01	11·02	10·16 – 11·80	7·29	6·75 – 7·65	4·73	3·80 – 5·12	–	–
PI 183451 01	10·75	9·53 – 11·67	7·21	6·83 – 8·05	5·23	4·54 – 5·62	–	–
Overall ranges for populations		**7·50 – 13·22**		**5·32 – 9·95**		**3·07 – 6·60**	–	–
Cajanus cajan								
PI 218066	5·29	5·00 – 5·72	5·05	4·60 – 5·41	3·98	3·57 – 4·22	2·38	2·12 – 2·82
Utnur AP DF 97–3	5·97	5·08 – 7·00	4·76	4·21 – 5·05	3·99	3·22 – 4·49	2·34	2·00 – 2·66
NSL 73128	5·13	4·59 – 5·67	5·06	4·45 – 5·77	3·93	3·44 – 5·65	2·31	2·03 – 2·69
PI 520598	6·15	5·78 – 6·44	5·20	4·72 – 5·55	4·21	3·95 – 4·64	2·39	2·03 – 2·86
Bellary 2/98 DF	6·14	5·21 – 6·81	5·73	4·98 – 6·41	4·45	3·39 – 5·08	2·56	2·30 – 2·88
Sudan 10/97 DF	5·92	4·66 – 6·76	4·97	4·34 – 5·46	4·32	3·70 – 4·89	2·17	1·83 – 2·60
Overall ranges for populations		**4·59 –7·00**		**4·21 – 6·41**		**3·22 – 5·65**		**1·83 – 2·88**
Vigna unguiculata								
Dharwad 4/3/97 DF	6·90	5·61 – 7·70	4·93	4·41 – 5·35	4·09	3·60 – 4·60	2·45	2·10 – 2·90
PI 180355 01	5·39	3·40 – 6·01	4·09	3·45 – 4·54	3·55	2·53 – 3·92	2·18	1·92 – 2·54
Overall ranges for populations		**3·40 – 7·70**		**3·45 – 5·35**		**2·53 – 4·60**		**1·92 – 2·90**
Vigna radiata								
PI 1730932	3·51	3·20 – 4·14	3·10	2·64 – 3·44	3·02	2·64 – 3·27	1·36	1·19 – 1·58
PI 473611 01	3·57	2·99 – 4·06	3·08	2·64 – 3·34	3·18	2·80 – 3·42	1·42	1·06 – 1·62
PI 473610 01	3·90	3·16 – 4·71	3·29	3·00 – 3·55	3·42	3·20 – 3·61	1·46	1·24 – 1·62
Karnataka 4/3/97 DF	4·03	3·60 – 4·61	3·30	2·76 – 3·65	3·19	2·39 – 3·70	1·56	1·26 – 1·84
Subramanian 1983		3·60 – 3·70		2·80 – 3·80				
Overall ranges for populations		**2·99 – 4·71**		**2·64 – 3·80**		**2·39 – 3·70**		**1·06 – 1·84**
Vigna mungo								
PI 377388	4·55	3·95 – 4·91	3·74	3·12 – 4·15	3·42	2·95 – 3·83	2·07	1·61 – 2·48
PI 164441 01	4·68	4·19 – 5·46	3·98	3·59 – 4·46	3·44	3·11 – 3·78	2·11	1·86 – 2·39
PI 164769 01	4·47	4·15 – 4·74	3·51	3·16 – 3·79	3·27	2·98 – 3·90	2·10	
Subramanian 1983		3·60 – 4·30		2·90 – 3·20				
Overall ranges for populations		**3·60 – 5·46**		**2·90 – 4·46**		**2·95 – 3·90**		**1·61 – 2·48**
Vigna aconitifolia								
PI 164419 01	4·21	3·98 – 4·46	2·68	2·40 – 2·91	2·61	2·32 – 2·85	1·08	0·89 – 1·25
PI 164530 01	4·05	3·55 – 4·45	2·48	2·25 – 2·67	2·41	2·00 – 2·60	1·07	0·90 – 1·32
PI 165482 01	3·77	3·07 – 4·30	2·49	2·10 – 2·86	2·44	1·81 – 2·80	1·08	0·87 – 1·36
PI 372355 01	3·98	3·57 – 4·26	2·51	2·16 – 2·75	2·42	2·22 – 2·66	1·24	1·00 – 1·52
Overall ranges for populations		**3·07 – 4·46**		**2·10 – 2·91**		**1·81 – 2·85**		**0·87 – 1·25**
Vigna umbellata								
PI 173933 01	5·89	5·04 – 6·46	3·63	3·19 – 3·94	2·85	2·45 – 3·15	3·06	2·64 – 3·46
Subramanian 1983		5·40 – 5·70		2·60 – 3·90				
Overall ranges for populations		**5·04 – 6·46**		**2·60 – 3·94**		**2·45 – 3·15**		**2·64 – 3·46**
Vigna angularis								
PI 175240 01	6·68	5·73 – 7·30	5·23	4·53 – 5·95	4·81	3·76 – 5·42	3·46	3·15 – 3·72
PI 527686 01	3·90	3·21 – 4·43	3·07	2·91 – 3·44	2·76	2·31 – 3·15	2·18	1·86 – 2·56
Subramanian 1983		5·50 – 6·70		3·60 – 4·30				
Overall ranges for populations		**3·21 – 7·30**		**2·91 – 5·95**		**2·31 – 5·42**		**1·86 – 3·72**
Vigna trilobata								
Grif· 13977 01	3·03	**2·68 – 3·41**	2·42	**2·16 – 2·61**	2·11	**1·94 – 2·36**	1·47	**1·24 – 1·66**
Wild pulse measurements								
Vigna radiata sublobata								
Ramaswami 386	3·12	2·90 – 3·30	1·42	1·20 – 1·60	1·88	2·20 – 1·70	1·94	2·20 – 1·60
Vigna mungo sylvestris								
Rao 7671	3·13	2·70 – 3·60	2·23	1·90 – 2·50	2·75	2·40 – 3·00	1·90	1·60 – 2·30
Macrotyloma uniflorum								
Jain 46660	3·95	3·90 – 4·00	2·90	3·30 – 2·50	1·23	1·00 – 1·40	0·75	1·00 – 0·60

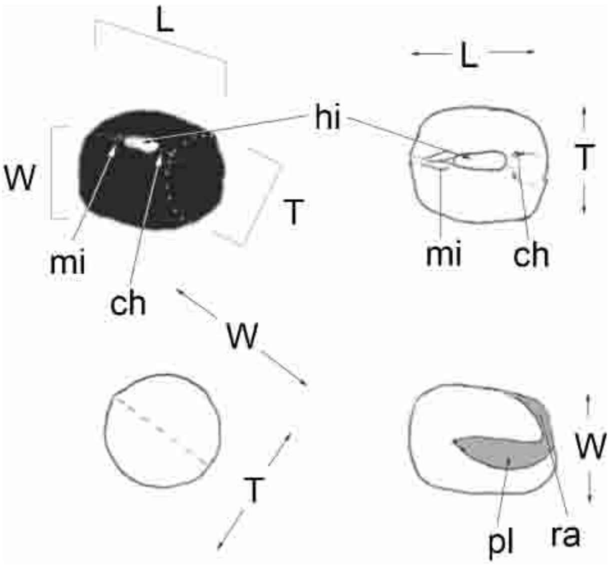

Figure 2 Diagrams of a pulse seed indicating descriptive anatomical terms used in the text and measurements taken on pulses.: L. length, W. width, T. thickness, hi. Hilum, mi. micropyle, ch. chalaza, ra. radicle (hypocotyl), pl. plumule. Strophiole is not illustrated, but see Fig. 5

identifiable in archaeological specimens. Pod dehiscence is not necessarily an absolute character, as is evident in modern cultivars of *Vigna radiata* and *Cajanus cajan*, some amount of natural pod dehiscence persists amongst some varieties (Kachroo and Arif 1970; Van der Maeson 1995) and, in any case, pod fragments that might reveal this trait have not been recovered archaeologically. Loss of germination inhibition is tied generally to a thinning of the seed coat (Butler 1989) although a comparative study of this has not been carried out on the Indian pulses under consideration. In addition, pulse testas are rarely preserved in the authors' Indian Neolithic material, although those on *Macrotyloma uniflorum* are more frequent and could repay future SEM study. Nevertheless a consideration of size change under domestication in *Vigna radiata* will be discussed further below.

Macrotyloma uniflorum (Lam.) Verdcourt

M. uniflorum (horsegram) is a widespread pulse in India today, where it is generally considered native. Although it is reported to be native to *Acacia* thickets of Indian savannah zones (Jansen 1989), detailed studies of the wild progenitor are unavailable, and thus the region of origin cannot be suggested with any certainty. Savannah woodlands are well documented as the favoured habitat for wild African populations which are unlikely to have ever contributed to the domesticated gene pool since this species is not cultivated in Africa, but they provide suggestive evidence for the wild forms' preferred ecology. While Mehra (1997) has suggested the southern and eastern peninsula as the region of origin, this is not backed up by reference to a detailed botanical study. Specimens in the Pune and Calcutta herbaria examined by Fuller indicate wild populations for Rajasthan (Mt. Abu) through parts of Madhya Pradesh, Maharashtra, and south-eastern Karnataka. By combining these limited collections with the distribution of dry tropical evergreen and savannah vegetation, a broad potential wild distribution can be inferred (Fig. 4). Horsegram has been widely reported in South Asian archaeobotany, and appears to have been widely cultivated from Southern India to Haryana, from *c.* 2500 BC, and the middle Gangetic basin, from *c.* 2000 BC. This species has been suggested to be part of the indigenous Southern Neolithic package (Fuller *et al.* 2001; 2004; Fuller 2002, 296), but an additional domestication centre is possible.

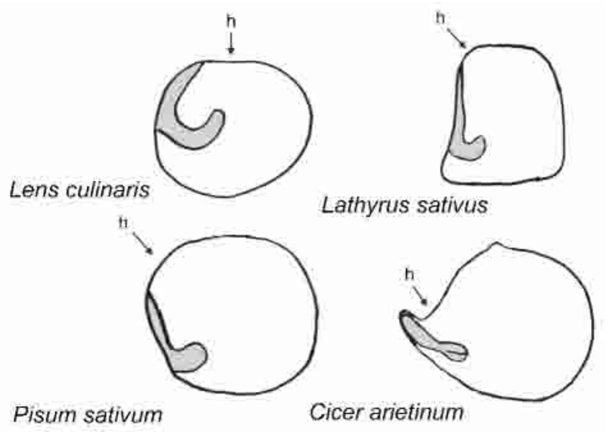

Figure 3 Line drawings of South-west Asian pulses of importance in prehistoric India, indicating the plumule form on split cotyledons. h = hilum

The seeds are roughly trapezoidal and sometimes somewhat reniform (kidney-shaped), although there appears to be a fair amount of variability in populations of modern comparative material (Fig. 5, Table 2) and amongst archaeological specimens. The seeds are flattish, with relatively thin cotyledons. The hilum is small and linear, located in a small, depression in the centre of the seed's edge. From the micropyle end of the hilum the edge of the seed is generally angular. On split embryos the embryo projects approximately one third of the distance across the cotyledon and is parallel to the base of the cotyledon. Archaeological specimens include a number of notably small seeds, which could

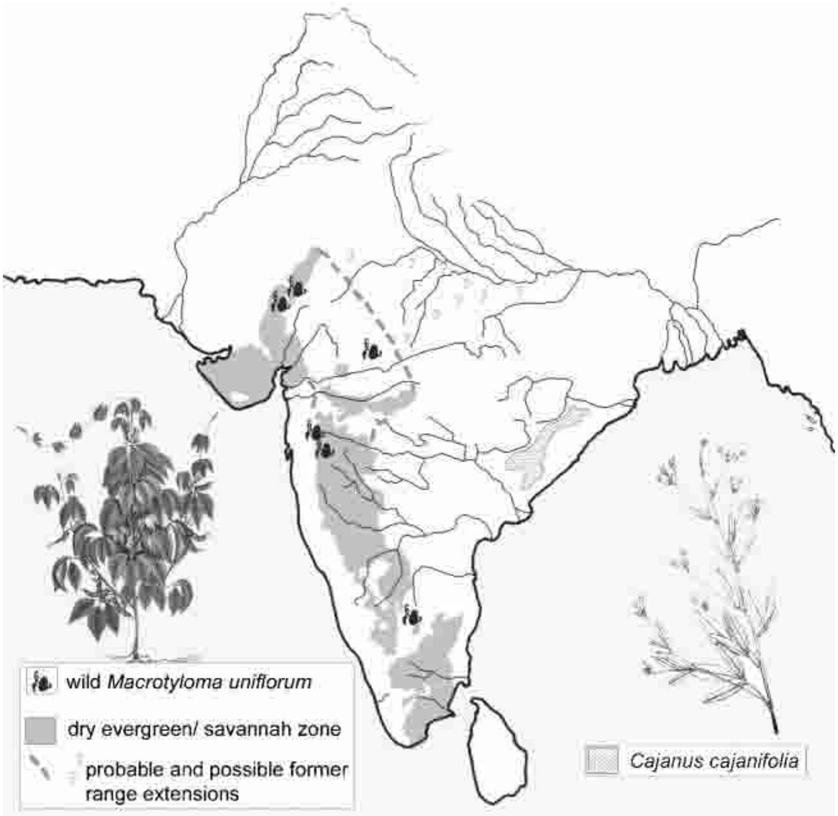

Figure 4 Map of wild distribution for *Macrotyloma uniflorum* and *Cajanus cajan*

represent immature seeds. Archaeological specimens from this study often retain part or all of their testa as well as hilum, a contrast with the other pulses (Fig. 6A). The testa often shows cracking, characteristically in a pattern emanating radially from the hilum side of the cotyledons.

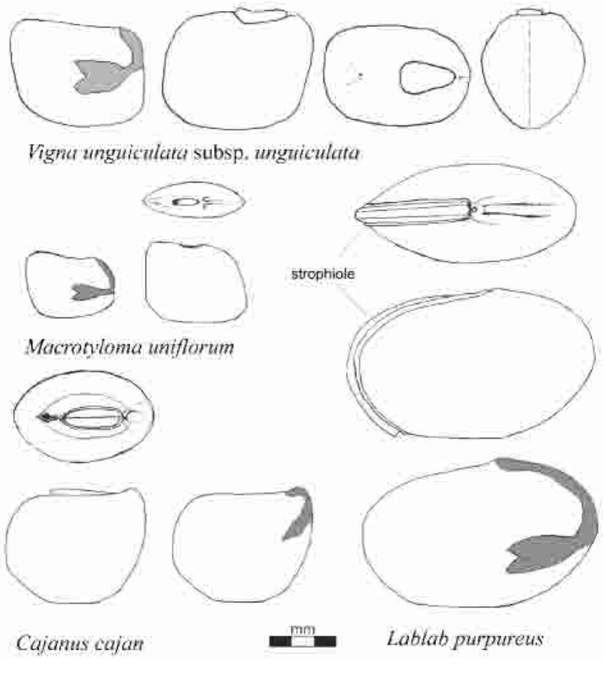

Figure 5 Line drawings of typical seeds of *Macrotyloma uniflorum*, *Lablab purpureus*, *Cajanus cajan*, *Vigna unguiculata*

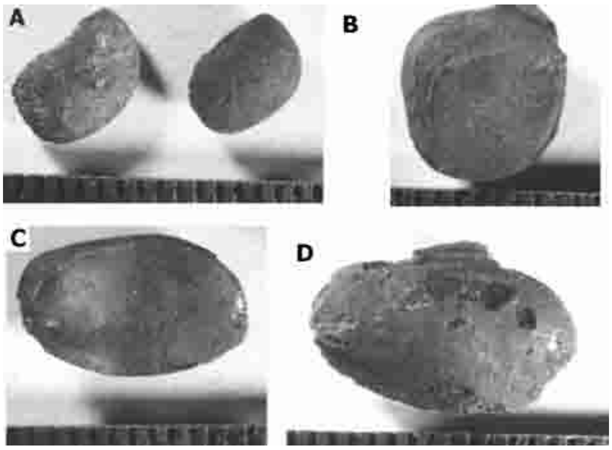

Figure 6 Examples of archaeological pulse specimens from Southern Neolithic site of Sanganakallu (SGK.98A.4). A. *Macrotyloma uniflorum* complete seeds. B. *Cajanus cf. cajan* split cotyledon, inner surface showing plumule. C. *Lablab purpureus* cotyledon inner surface showing plumule. D. *Lablab purpureus* with partial preservation of strophiole/hilum. Scale increments = 1/2 mm

Cajanus cajan (L.) Millsp.

Cajanus cajan (pigeonpea) is a major cultivar throughout the tropics today. The identification of wild progenitor populations, *Cajanus cajanifolia* (Haines) Van der Maeson in eastern Peninsular India is now well established (Fig. 4, based on Van der Maeson 1986; 1995). In addition there are several other species of *Cajanus* (formerly *Atylosia*) that occur in India, especially in the wet and dry deciduous forests of the Peninsula (De 1974; Van der Maeson 1986). More extensive comparative study of the seeds of these species is needed. The seeds in this genus are flat on the hilum end, although the hilum sometimes has a stropile which forms a ring around it. While this is found in wild species, it is absent or highly reduced in most populations of the domesticate. In the absence of hilum preservation it may be difficult definitively to distinguish the domesticate from wild taxa, although wild species tend to have rather flatter seeds. The seeds of pigeonpea come in a range of shapes, from reniform to round to somewhat squarish. Split cotyledons can be readily identified on the basis of a distinctive diagonal plumule, like an 'apostrophe' (Figs. 5, 6B).

Pigeonpea has still been reported from relatively few sites in India, including Tuljapur Garhi, Peddamudiyam and Sanganakallu, all from the Deccan in the mid- to late 2nd millennium BC (Fuller 1999; Fuller *et al.* 2001; 2004). The examples from the latter site show clearly the general *Cajanus* shape and the distinctive plumule placement (Fig. 5), but can not be clearly distinguished as not wild. Nevertheless, the occurrence on this site argues for identification with the crop. This is because the site lies in a particularly dry region where wild *Cajanus* spp. are not known (Singh 1988), and would have been subject to broadly similar climatic conditions during the period of Neolithic occupations (Fuller and Korisettar 2004). Important new evidence has been found in flotation samples collected in September 2003 from Gopalpur and Golbai Sasan, sites in Coastal Orissa (Harvey *et al.* in press; Harvey in press). Here from a Late Neolithic/Early Chalcolithic level, *Cajanus* cotyledons have been recovered (directly dated to 1400–1300 BC). Pigeonpea has thus far proven absent from sites in the Ganges basin until into the 1st millennium BC. Taken together the available evidence suggests that pigeonpea was a rather later domesticate, perhaps of the middle 2nd millennium BC when sedentary settlement was first established in Orissa adjacent to the area of the species' wild distribution represented by Gopalpur and Golbai.

Lablab purpureus (L.) Sweet

L. purpureus (hyacinth bean) is widely cultivated in India for its seeds (the traditional variety *L. purpureus* var. *lignosus* (L.) Prain), with some varieties selected for edible green pods (variety *L. purpureus typicus* Prain). The seeds are generally reniform and the lateral ends are generally more smoothly curved and cotyledons more convex than *Macrotyloma* (Figs. 5, 6C, Table 2). However, form is quite variable, and more or less round seeds occur occasionally, causing possible confusion with some seeds of *Cajanus cajan* if judged on the basis of shape alone. The most distinctive trait is a very long hilum, enclosing nearly half the circumference of the grain, covered by a keeled strophiole (Fig. 6D). The hilum/strophiole, however, is rarely preserved although even fragmentary preservation is highly distinctive. Even when not preserved, faint marks on the curved edge of the charred cotyledon often betray where the hilum had been. The chalaza, formed by the hypocotyls (radicle) of the embryo, is often clearly visible in charred specimens. The embryo curves around the end of the seed and projects into the seed in a nearly perpendicular fashion, similar to the placement in *Macrotyloma* and *Vigna* spp. The embryo projects up to one third the distance across the seed (Figs. 5, 6C).

Contrary to many reference books *Lablab* is not of Indian origin. Floristic survey suggests an east African origin (Verdcourt 1970; 1971; Fuller 2002, 291; 2003a), which is now clearly supported by DNA evidence (Pengelly and Maass 2001; Maass *et al.* 2005), and a few free-growing populations in southern India appear to be early feral lineages. Unfortunately archaeobotanical data for the early use of this species in Africa is lacking. Reported finds include those from Meroitic Nubia at Umm Muri and Qasr Ibrim (in the first four centuries of the current era) (Fuller 2004; Clapham and Rowley-Conwy, in press), as well as the Geldud rock shelter amongst a largely wild plant assemblage of the 1st century (Smith and Jacobsen 1995). Recent direct AMS dates on specimens from South India confirm hyacinth bean back to 1500–1400 BC at Hallur, 1500–1400 BC at Hiregudda, and 1400–1300 BC at Sannarachamma (Table 3). The earliest find in South Asia may be that from Mahorona, although further dating evidence is needed from this site.

Table 3 **Direct AMS dates on pulse seeds from Indian sites (Fuller *et al.* in press). Calibrations performed with Oxcal 3·3 (Bronk Ramsey 2001; 2003), based on atmospheric calibration data of Struvier *et al.* (1998). Calibrations are indicated in 1- σ ranges with a sterix by what we interpret as the most plausible range. Dates were performed in 2004 by Accelerator Mass Spectrometry (AMS) by Rafter Radiocarbon Laboratory (New Zealand) or Peking University, Beijing, Institute of Heavy Ion Physics and School of Archaeology and Museology. All dates from Orissa and Uttar Pradesh were conducted at the Oxford University Radiocarbon Accelerator Unit with the support of a NERC grant**

Site and culture	Context no.	Lab no.	Radiocarbon age	1- σcalibration
Cajanus cajan				
Gopalpur, Orissa, Chalcolithic	GPR 2	OxA-14128	3035±31	1395–1210 BCE
Cicer arietinum				
Piklihal Southern Iron Age/Early Historic	PKL.03B 20–50 cm	R 28680/28	1747±30	240–340 CE
Lablab purpureus				
Sannarachamma (Sanganakallu) Southern Neolithic/Megalithic	SAN 1147	R 28680/1	2973±35	1270–1120 BCE
Southern Neolithic/Megalithic	SGK.98A-4	R 28680/5	3042±30	1380–1210 BCE
Southern Neolithic/Megalithic	SGK.98B-6	BA05775	3105±40	1430–1310 BCE
Hiregudda Southern Neolithic/Megalithic	HGD.03B-1	R 28680/14	3058±30	1390–1260 BCE
Hiregudda Southern Neolithic	HGD.03F-3	R 28680/16	3235±30	1525–1445 BCE
Hallur Southern Neolithic	HLR.98A-7	BA04499	3300±40	1620–1520 BCE
Hallur Southern Neolithic	HLR.00 +50cm	R 28680/30	3154±30	1495–1475 BCE 1450–1395 BCE
Lens culinaris				
Mahagara, Uttar Pradesh, Neolithic	MGR 39	OxA-14092	3238±29	1545–1430 BCE
Piklihal Southern Neolithic	PKL.03B 100–130cm	BA05772	3445±40 BP	1880–1690 BCE
Macrotyloma uniflorum				
Piklihal Southern Neolithic	PKL.03D-4	R 28680/26	3366±30	1740–1610 BCE
Piklihal Southern Neolithic	PKL.03B 100–130cm	BA05771	3405±40 BP	1750–1630 BCE
Piklihal Southern Neolithic	PKL.03B 70–100cm	BA05770	3430±40 BP	1870–1840 BCE 1810–1680 BCE
Piklihal Southern Neolithic	PKL.03B 50–70cm	BA05774	3435±40 BP	1870–1680 BCE
Hirregudda Southern Neolithic	HGD.03F-6	R 28680/18	3250±30	1600–1560 BCE 1530–1450 BCE
Hanumantaraopeta Southern Neolithic	HRP97·1–3	R 28680/34	3259±40	1610–1450 BCE
Hallur Southern Neolithic	HLR.98A-8	BA05777	3435±40 BP	1870–1680 BCE
Hallur Southern Neolithic	HLR.00 +30cm	R 28680/29	3221±30	1520–1445 BCE
Hallur Southern Neolithic/ Megalithic	HLR.98B	BA04393	2835±30	1015–920 BCE
Hattibelagallu Southern Neolithic	HBG.98C-3	BA05778	3475±40 BP	1880–1740 BCE
Tekkalakota Southern Neolithic	TKT.98B-2W	BA05784	3545±80 BP	2010–1760 BCE
Velpumudugu Southern Neolithic	VPM.03A-3	R 28680/24	3029±35	1380–1210 BCE
Vigna radiata				
Hanumantaraopeta Southern Neolithic	HRP97·1–5	R 28680/35	3374±35	1740–1610 BCE
Hanumantaraopeta Southern Neolithic	HRP97·1–6	R 28680/36	3365±30	1740–1610 BCE
Sanyasula Gavi Southern Neolithic	SSG B-5	R 28680/33	3515±35	1890–1760 BCE
Tekkalakota Southern Neolithic	TKT.98A-3	BA05778	3430±45 BP	1880–1680 BCE
Golbai Sasan, Orissa, Chalcolithic	GBSN 13D	OxA-14135	2920±29	1215–1005 BCE
Mahagara, Uttar Pradesh, Neolithic	MGR 49	OxA-14158	3270±29	1625–1485 BCE

Table 4 The distribution of pulses reported on archaeological sites in South Asia, broken down by region and period

			Southwest Asian				Indian						African		
map no.	site	age	Pisum sativum	Lens culinaris	Lathyrus sativus	Cicier arietinum	Vigna sp. (mungo/radiata)	Vigna radiata	Vigna mungo	Vigna aconitifolia	Cajanus cajan	Macrotyloma uniflorum	Lablab purpureus	Vigna unguiculata	source
	Northwest														
1	Bir-Kot-Ghwandai	1700–1400 BC		x											Costantini 1987
3	Burzahom	2400–1700 BC	x	x											Lone *et al.* 1993
	"	1700–1000 BC		x											"
	"	1000–600 BC	x	x											"
	"	600BCE–200 CE	x	x											"
5	Gufkral	ca. 1200 BC	x	x											Kajale 1989b
7	Hund	0–800 CE	x	x	x		x	x	x			x			Fuller, *et al.* unpublished
	"	800–1400 CE	x	x	x		x	x	x						"
	"	1400–1600 CE		x	x		x	x	x						"
89	Kanishpur	3200–2000 BC	x	x											Pokharia and Saraswat 2004
2	Loebanhr 3	1700–1400 BC	x	x											Costantini 1987
4	Semthan	1500–600 BC		x				x	x						Lone *et al.* 1993
	"	600–200 BC	x	x				x	x						"
6	Tarakai Qila	3000–2000 BC		x											Thomas 1999
	Greater Indus Valley														
12	Balu	2600–2300 BCE					x	(x)				x			Saraswat 2002; Saraswat and Pokharia 2002
	"	2300–1900 BCE	x	x	x		x	(x)				x			"
23	Burthana Tigrana	2500–2000 BCE					x	x	x	x		x			Willcox 1992; unpublished
21	Chanudaro	2500–2000 BCE	x												Vishnu-Mittre and Savithri 1982
11	Daulatpur	2200–1700 BCE					x								"
8	Harappa	2500–2000 BCE	x	x	x	x	x					?			Weber 1997; 1999; 2003
15	Kalibangan	2600–2000 BCE	x			x									Vishnu-Mittre and Savithri 1982
16	Kunal	2900?–2700 BCE		x											Saraswat and Pokharia 2003
	"	2700–2400 BCE	x	x											"
	"	2400–2000 BCE ?	x	x	x	x	x	(x)				x			"
13	Mahorana	2200–1900 BCE ?		x									x		Vishnu-Mittre *et al.* 1986b; Saraswat 1991: Saraswat and Chanchala 1994
24	Mangali Ludawala	1500–1900 CE					x					x			Willcox 1992; unpublished
17	Miri Qalat	4000–3500 BCE		x											Tengberg 1999
	"	3000–2500 BCE		x											"
	"	2500–2000 BCE	x	x											"
25	Mitathal	2000–1400 BCE					x	x	x	x		x			Willcox 1992; unpublished
20	Mohenjodaro	2500–2000 BCE	x												Vishnu-Mittre and Savithri 1982
19	Nausharo	2500–2000 BCE		x											Costantini 1990
22	Pirak	1900–1500 BCE				x									Costantini 1979
9	Rohira	2500–2000 BCE		x								x			Saraswat 1986
10	Sanghol	2200–1500 BCE	x	x	x							x	x		Saraswat 1997
	"	200 BC–250 CE	x	x	x	x		x	x			x	x	x	Saraswat and Pokharia 1998; Saraswat 1997
	Indo-Gangetic divide/Gangetic Doab													x	
28	Atranjikhera	2000–1500 BCE			x	x									Saraswat 1980
	"	2000–1000 BCE			x	x									Chowdhury *et al.* 1977

Table 4 ***Continued***

			Southwest Asian				Indian						African		
map no.	**site**	**age**	**Pisum sativum**	**Lens culinaris**	**Lathyrus sativus**	**Cicier arietinum**	**Vigna sp. (mungo/radiata)**	**Vigna radiata**	**Vigna mungo**	**Vigna aconitifolia**	**Cajanus cajan**	**Macrotyloma uniflorum**	**Lablab purpureus**	**Vigna unguiculata**	**source**
28	Atranjikhena	500–250 BCE			x	x	x								Chowdhury *et al.* 1977
26	Lal Qila	1800–1300 BCE		x											Kajale 1995
14	Hulas	1800–1300 BCE	x	x	x	x		x				x		x	Saraswat 1993a
	Central Himalayas (Garhwal/ Nepal)													x	
27	Ufalda	500–700 CE		x			x	x		x		x			Fuller *et al.*, unpublished
88	Mebrak Cave	300 BCE–100 CE	x	x									x		Knörzer 2000
	Middle Ganges Valley														
42	Chopani-Mando	3500?–2500? BCE					x	x							Fuller and Harvey, unpublished
41	Charda	1000–300 BCE	x	x	x		x	x	x		x	x			Chanchala 2002
	"	300 BCE–100 CE	x	x	x		x	x	x						"
	"	100–600 CE	x	x	x		x	x	x						"
	"	600–1000 CE				x									"
32	Chirand	2200–1500 BCE	x												Vishnu-Mittre 1972
38	Hulaskhera	700–500 BCE						x							Chanchala 1992
	"	200 BCE–250 CE	x		x			x							"
29	Imidh-Kurd	I. ?–1300 BCE	x	x	x			x							Saraswat 1993b
	"	ii. 1300–800 BCE		x		x		x							"
40	Khairadih	700–200 BCE	x		x	x		x							Saraswat *et al.* 1990
37	Kausambi	550–250 BCE	x												Chanchala 1995
44	Koldihwa	1900–1400 BCE		x			x		x						Harvey *et al.* 2005
43	Mahagara	1900–1400 BCE		x	x		x	(x)	x						Harvey *et al.* 2005
33	Malhar	I. 2200–1600 BCE	x	x	x			x	x						Saraswat 2003–2004; Tewari *et al.* 2003–2004
	"	II. 1600–800 BCE	x	x	x			x				x			"
31	Manjhi	250BC–250 CE	x	x	x				x						Chanchala 2001
30	Narhan	1300–800 BCE	x	x	x	x		x		x		x	x		Saraswat *et al.* 1994
		800–300 BCE	x	x	x	x		x	x			x	x		"
39	Radhan	1000–250 BCE	x												Kajale and Lal 1989
90	Saunphari	IA. 1000–700 BCE	x	x	x				x	x		x			Chanchala 2004
		IB. 700–100 BCE	x	x	x			x	x			x			
		II. 100–300 CE	x	x				x	x	x		x			
34	Senuwar	IA. 2000–1800 BCE	x	x	x										Saraswat 2004
	"	IB. 1800–1400 BCE	x	x	x	x		x							"
	"	II. 1200–600 BCE	x	x	x	x		x		x					"
36	Taradih	2000–1500 BCE(?)	x			x	x								Kajale 1991
35	Tokwa	1900–1400 BCE					x	(x)							Fuller, in Misra *et al.* 2001: 65
	Gujarat														"
50	Babar Kot	2000–1700 BCE		x	x				x						Reddy 1994; 2003
51	Oriyo Timbo	1700–1400 BCE							x						"
49	Rojdi	2600–2200 BCE							x						Weber 1991
	"	2000–1700 BCE	x	x	x			x	x			x			"
	Rajasthan/Madhya Pradesh														
45	Balathal	2500–2000 BCE	x					x	x						Kajale 1996a
	"	500 –300 BCE	x			x		x	x						
46	Dangwada	2000–1500 BCE		x			x								Vishnu-Mittre *et al.* 1984
	"	300 BCE–300 CE		x	x										"
47	Kayatha	2300–1400 BCE										x			Vishnu-Mittre *et al.* 1985
48	Noh	500BCE–300 CE					x					x			Vishnu-Mittre and Savithri 1974
	Maharashtra														
61	Adam	1000–500 BCE			x										Kajale 1994

Table 4 ***Continued***

			Southwest Asian				Indian						African		
map no.	site	age	Pisum sativum	Lens culinaris	Lathyrus sativus	Cicier arietinum	Vigna sp. (mungo/radiata)	Vigna radiata	Vigna mungo	Vigna aconitifolia	Cajanus cajan	Macrotyloma uniflorum	Lablab purpureus	Vigna unguiculata	source
61	Adam	500–300 BCE		x			x					x	x		Kajale 1994
	"	300 BC–50 CE	x	x	x		x								"
56	Apegaon	1700–1200 BCE	x	x	x			x	x			x	x		Kajale 1979
65	Bhagimohari	1000–250 BCE	x	x	x		x				x	x	x		Kajale 1989b
62	Bhatkuli	300 BCE–250 CE				x									Vishnu-Mittre and Gupta 1968b
59	Bhokardan	300 BCE–250 CE	x	x	x	x	x				x		x		Kajale 1974
55	Daimabad	2000–1700 BCE		x											Kajale 1977a
	"	1700–1500 BCE	x	x	x							x	(x)	x	Kajale 1977a; Vishnu-Mittre *et al.* 1986a
	"	1500–1100 BCE	x	x	x							x	(x)	x	Kajale 1977a; Vishnu-Mittre *et al.* 1986a
57	Inamgaon	1700–1500 BCE	x	x								x	x		Kajale 1988b
	"	1500–1200 BCE	x	x	x							x	x		"
	"	1200–900 BCE	x	x	x	x		x				x	x		"
53	Kaothe	*c.* 2200 BCE							x			x			Kajale 1990
63	Kaundinyapura	1st M. CE	x		x										Vishnu-Mittre 1968
54	Naikund	1000–250 BCE	x	x			x								Kajale 1982
52	Navdatoli	1500–1200 BCE		x	x		x								Vishnu-Mittre 1961
58	Nevasa	150 BCE–200 CE	x	x	x	x	x					x	x		Sankalia *et al.* 1960; Kajale 1977b
60	Paithan	200 BCE–700 CE		x	x	x	x	x	x	x	x	x	x		Fuller, unpublished
66	Terr	250 BCE– 250 CE	x	x	x	x	x					x			Vishnu-Mittre *et al.* 1971
64	Tuljapur Garhi	1500–1200 BCE		x	x	x		x	x		x	x	x		Kajale 1988a; 1996b
	Orissa														
67	Gopalpur	1400–600 BCE									x	x			Harvey, unpublished
68	Golabai Sassan	1400–600 BCE					x	x	x		x	x			Harvey, unpublished
	South India														
71	Budihal	2300–1700 BCE										x			Kajale and Eksamberkar 1997
70	Hallur	2000–1000 BCE					x	x	x			x	x		Kajale 1989a
	"	1800–1400 BCE					x	x	x			x	x		Fuller *et al.* 2004
77	Hanumantaraopeta	1700–1400 BCE					x	x	x			x			"
75	Hatibellagalu	2200–1800 BCE ?					x	x				x			"
85	Hiregudda	1900–1500 BCE					x	x				x			"
	"	1500–1300 BCE					x	x				x	x		"
78	Injedu	1700–1400 BCE										x			"
87	Kodumanal	300 BCE–100 CE					x	x	x			x	x	x	Cooke *et al.* 2005
83	Kurugodu	1800–1200 BCE ?					x	x				x			Fuller *et al.* 2004
80	Peedamudiyam	1700–1400 BCE					x	x	x			x			Fuller *et al.* 2004
86	Perur	300 BCE–300 CE					x	x	x			x	x	x	Cooke *et al.* 2005
72	Piklihal	1800–1200 BCE		x			x	x			x	x	x		Fuller, unpublished
	"	500 BCE–200 CE		x	x	x	x	x				x	x		"
69	Ramapuram	1700–1400 BCE					x	x	x				x		Venkatasubbaiah & Kajale 1991
79	Rupanagudi	1700–1400 BCE					x	x							Fuller *et al.* 2004
84	Sangankallu	1900–1500 BCE					x	x				x			"
	"	1500–1200 BCE			?		x	x			x	x	x		"
74	Sanyasula Gavi	1900–1700 BCE					x	x							Fuller, unpublished
82	Tekkalakota	1800–1400 BCE					x	x				x			Fuller *et al.* 2004
69	Veerapuram	500 BCE–400 CE	x						x			x	x		Kajale 1984

Vigna unguiculata (L.) Walp.

Cowpea (*Vigna unguiculata*) is widely cultivated in the tropics and subtropics today, including the 'black-eyed pea' varieties. This species is indigenous to Africa and was most likely domesticated in West Africa (Ng 1995; Fuller 2003a). The earliest evidence yet found in Africa is of probable specimens from the Kintampo culture (see D'Andrea and Casey 2002). Finds from India are probably earlier than this (Fuller 2003a). Actual reports of cowpea in South Asia have been few (Fuller 2002, see below, Table 4), although an unwary perusal of the literature might suggest otherwise. An unfortunate taxonomic confusion has muddied the literature as South Asian archaeobotanical reports of '*Dolichos biflorus*' have been converted to the nomenclature of *Vigna unguiculata* (e.g. Weber 1991; Reddy 1994; 2003; Kroll 1996; 1997; 1998). While the synonymy of *D. biflorus* L. and *V. unguiculata* (L.) Walp. is correct, the conventional use of '*D. biflorus*' in the Indian botanical and agricultural literature (which follows Roxburgh's (1832) mis-interpretation of Linneaus) is as a synonym for *D. uniflorus* Lam., the crop known as horsegram, and thus these should be correctly converted to *Macrotyloma uniflorum* (Lam.) Verdc. (see Purseglove 1968; Verdcourt 1970; Smartt 1990; Fuller 2002).

V. unguiculata seeds are quite distinct from horsegram (Fig. 5; Table 2). The most widespread cultivars are in the cv. groups *unguiculata* and *biflorus*, and their shape is sub-rectangular, with a somewhat triangular cross-section, which tapers away from the hilum edge. The yard-long beans in cv. *sesquipedalis* are generally flattish, but reniform rather than rectangular. The hilum is ovate and generally placed asymmetrically on the hilum edge, a trait which differs from *M. uniflorum* and the other *Vigna* crops (see below).

Asian *Vigna* spp., sub-genus *Ceratotropis* (Piper) Verdcourt

Quite distinct from the form of *V. unguiculata* (L.) Walp. are the seeds of various cultivated *Vigna* species in the subgenus *Ceratotropis* (Fig. 7; Table 2). These seeds are generally cylindrical, being ovate in lateral view and nearly round in cross-section. The most readily separable of those examined is *V. angularis* (Willd.) Ohwi and Ohashi (a name *misapplied* by Weber 1991) which has a particularly long hilum displaced towards one end and a slightly trianguloid cross-section. *V. aconitifolia* (Jacq.) Marechal has a much smaller and shorter hilum that is usually slightly concave. *V. aconitifolia* is narrower and longer than other taxa, i.e. with a L:W ratio of >1·5, whereas the L:W ratio of other taxa is 1·2–1·5. The distinction is great enough that it is unlikely to be obscured by shrinkage. *V. trilobata* is very similar in proportions (e.g. in L:W ratio) and shape to the two main South Asian domesticated *Vigna*, but is significantly smaller and differs in having a long hilum (relative to length) that is raised. In *V. trilobata*, which has much smaller seeds, the chalazal end of the cotyledons is often thicker and wider than the micropylar end.

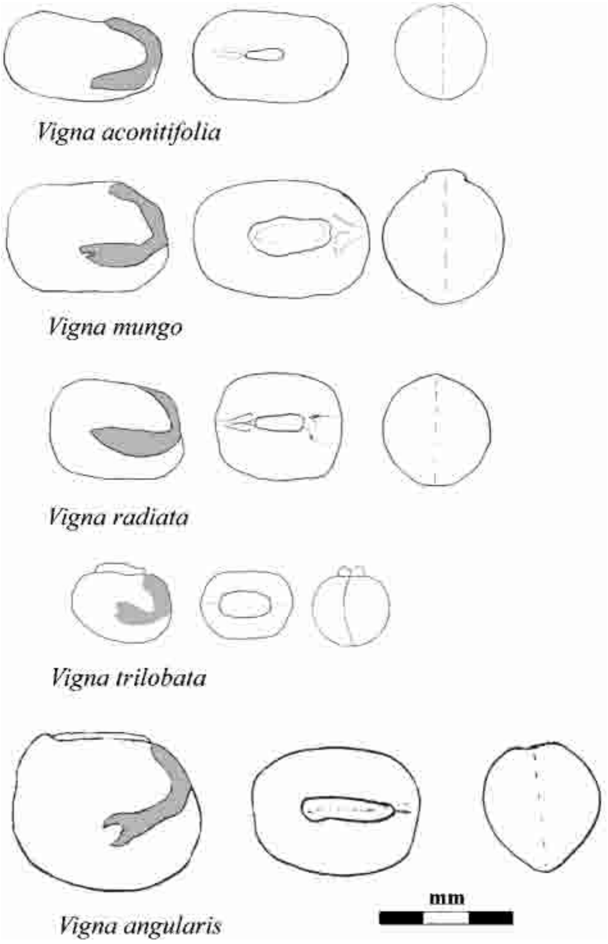

Figure 7 **Line drawings of representative seeds of cultivated *Vigna* spp. of the sub-genus *Ceratotropis***

The two most important *Ceratotropis* crop species, V. *radiata* (L.) Wilzcek (green gram, mung) and *V. mungo* (L.) Hepper (black gram, urd or urid), share a large number of characters in common and the size and general shape of their seeds overlap. Despite some earlier claims that *V. mungo* has squarer seeds (e.g. Vishnu-Mittre 1961), this is a not a reliable distinction among modern populations examined. General size and shape does not appear to be adequate to distinguish these two species. Although

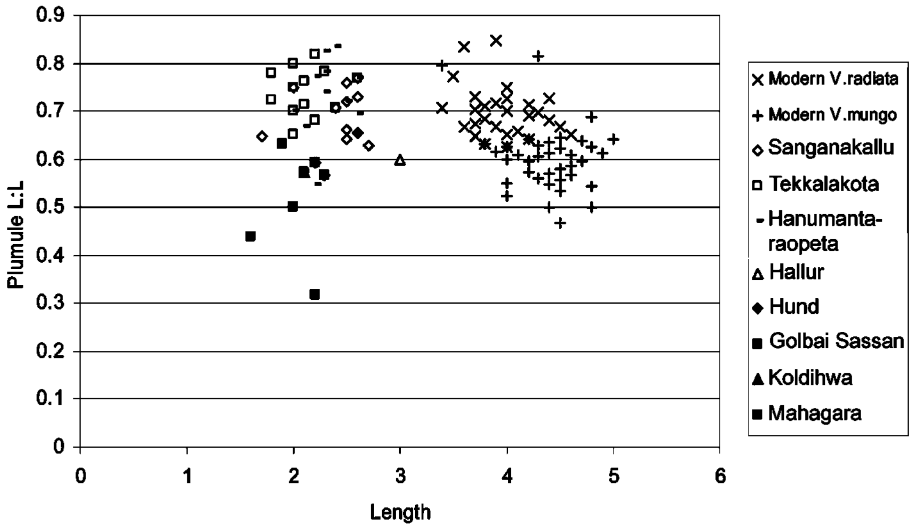

Figure 8 Scatter plot of seed length against ratio plumule length to seed length for modern populations of *Vigna radiata* and *Vigna mungo*, as well as archaeological specimens from Southern Indian Neolithic sites and Orissan Neolithic sites

there is a statistical distinction in length between *V. radiata* and *V. mungo* (see Fig. 8), this is unreliable for archaeological identification due to an inability to control the extent of size change with charring and the significance of gradual size increases that are likely to have occurred after domestication. If the hilum is preserved, which is extremely rare in the samples studied, the distinction between *V. radiata* and *V. mungo* is easily made since *V. mungo* and its wild progenitor 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; Chandel *et al.* 1984; Poehlman 1991, 20).

The only widely applicable approach to distinction relies on the statistical comparison of ratios of plumule length to overall length measured on split cotyledons (as used by Kajale 1979; 1984; 1988b; 1996a). Although there is a statistical overlap between *V. mungo* and *V. radiata* on this trait there are nevertheless cut-off values below and above which only one species is likely. In *V. aconitifolia* plumule length is usually less than half cotyledon length. A plot of plumule length: seed length ratios in two modern populations against seed length is shown in Fig. 8 alongside some representative specimens from Southern Neolithic sites (from Fuller 1999). The Neolithic specimens form a single population falling in the *V. radiata* and overlap zone. The two outlier specimens indicated as *V. mungo* also have remnants of the *mungo* type seed coat. Therefore the bulk of the archaeobotanical specimens from the southern Neolithic study appear to form a single population falling in the *V. radiata* and overlap zone. For this reason virtually all *Vigna* sp. cotyledons from these sites were assigned to *V. radiata* (Fuller 1999). Only three probable specimens of *V. mungo* were identified on the basis of short plumules or traces of *mungo*-type testa patterns. Specimens from Neolithic sites in Northern and Eastern India indicate the presence of both *V. radiata* and *V. mungo.*

Although less generally applicable to archaeobotanical finds, another criterion for distinction relies on epidermal cell patterns. The difference in epidermal cell forms on the testas of *V. radiata* and *V. mungo* has been recognised in taxonomic studies (Bose 1932a; 1932b; Chandel *et al.* 1984; Poehlman 1991, 17–18). *V. radiata* has rows of very long, thin rectangular cells, first described by Bose (1932a) as ‘fine, wavy ridges’, whereas those in *V. mungo* are shorter, wider and more ovate. Other *Vigna* spp. examined also appear to have these squarish cells, suggesting that elongate cells of *V. radiata* are a characteristic, evolutionarily-derived trait. These patterns are readily observable on fresh material at magnifications of x40, although they are more readily apparent at higher magnifications (Fig. 9). Fragments of the seed coat are occasionally preserved on archaeological specimens. Examples were noted from several contexts in the study of Southern Neolithic material and Golbai Sasan thus confirming the evidence of plumule length ratios.

Vigna radiata and *V. mungo* derive from distinct wild progenitors (Arora *et al.* 1973; Lukoki *et al.* 1980; Miyazaki 1982; Chandel *et al.* 1984; Poehlman 1991; Lawn 1995; Kaga *et al.* 1996; Ghafoor *et al.* 2002). In older taxonomic treatments this distinction amongst wild populations was not recognised and

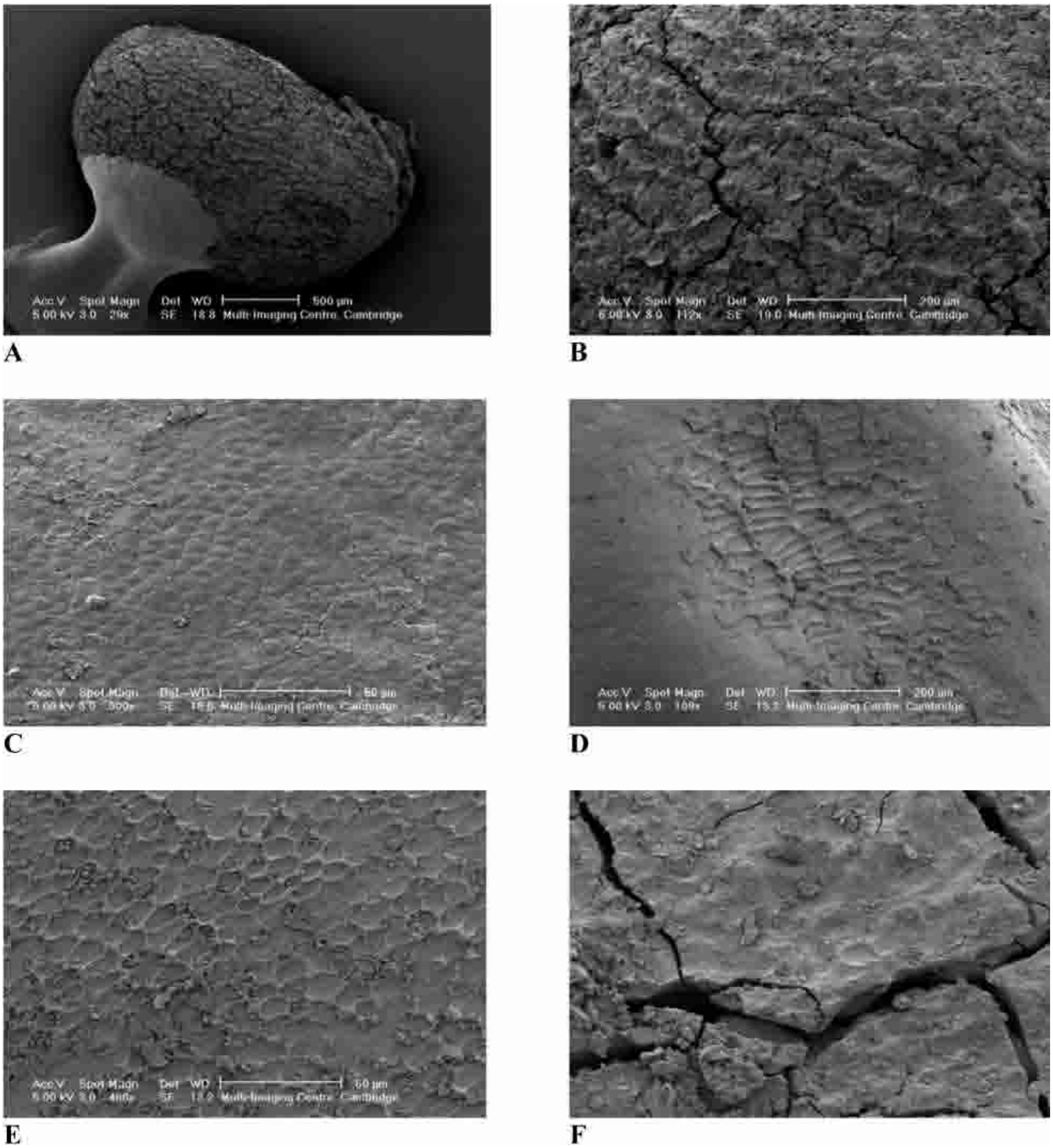

Figure 9 **Archaeological specimen of *Vigna radiata* from Sanganakallu (SGK.98B.4) (A–B) with preserved testa showing distinctive pattern of wavy-rows of elongate cells. Testa patterns of modern *Vigna* spp. are shown for comparison (C (*V. mango*), D (*V. radiata*) and E (*V. triloba*)). Other *Vigna* species have smaller, regular quadrangular cells. Possible traces of this pattern can been seen on a specimen from Southern Neolithic Hallur, which also has a short plumule (F)**

both were grouped under *Phaeseolus sublobatus* or *Vigna radiata* subsp. *sublobata sensu lato*. Thus it is unclear from published floristic sources whether there are any differences in their wild distribution. More recent recognition of distinct wild progenitors has implied some likely differences in their distribution (Arora *et al.* 1973; Sharma *et al.* 1977; Ignacimuthu and Babu 1985; Babu *et al.* 1988; Arora and Mauria 1989; with some provisional interpretation in Fuller 2002; 2003b; Fuller and Korisettar 2004). What is needed, however, is botanical field investigations and reinvestigations of older herbarium collections. Initial work towards a reassessment, based on examining wild specimens held in the Indian National Herbarium in Calcutta (CAL) and the Western Regional Herbarium in Pune (BSI) by Fuller,

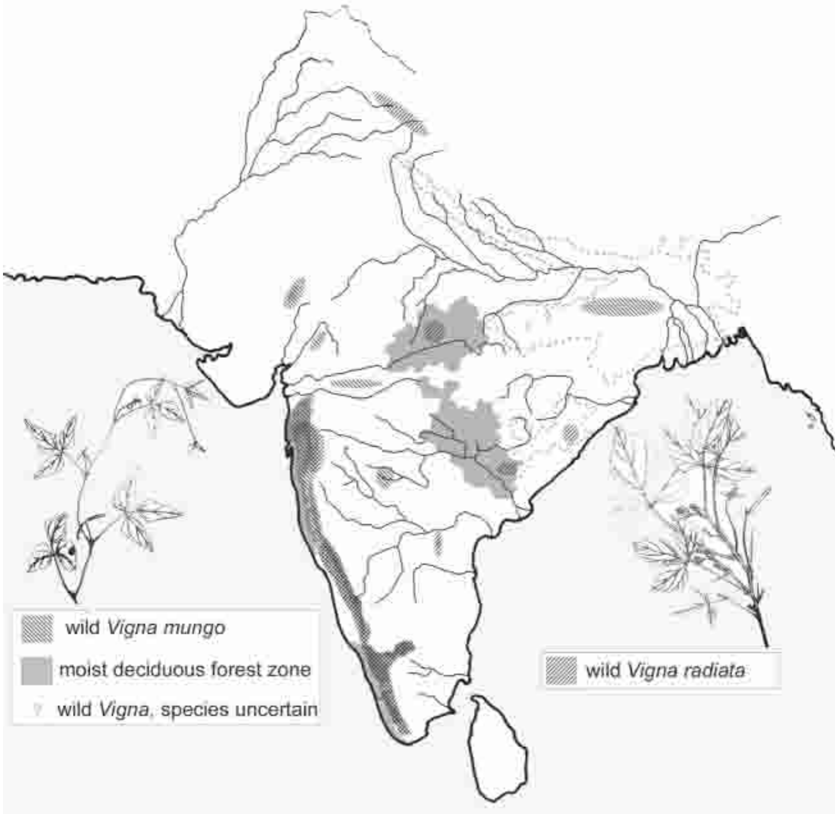

Figure 10 Map of wild distribution of *Vigna radiata* and *Vigna mungo*

suggests that there are indeed distinct distributions but partly overlapping distributions, as indicated in Fig. 10. In general the northern Western Ghats and populations extending into the hills of Rajasthan to Mount Abu are home to wild *Vigna mungo* var. *silvestris* Lukoki, Marechal and Otoul, as are at least some of the central Indian hills. In the southern Western Ghats, this wild form co-occurs with *Vigna sublobata* (Roxb.) Verdc. *sensu stricto*. Meanwhile only wild *V. radiata* occurs sporadically in some of the Eastern Ghats hills and in the Western Himalayan foothills. While further botanical investigation is warranted, this new distribution data provides a basis for assessing the archaeological evidence. Of these two it is only the mungbean (*V. radiata*) that was a major Neolithic crop in South India. By contrast the earliest *V. mungo* is at Rojdi in Gujarat. Later finds in the early 2nd millennium BC in Maharashtra and the middle Ganges, suggest an origin towards the northern Peninsula and western India with subsequent eastward dispersal. The Southern Neolithic's near exclusivity of *V. radiata*, however, suggests domestication in an area where only this wild type occurs. Thus it is now necessary to revise our ideas about the domestication of the mungbean along the Western Ghats and look instead towards to the discontinuous hills of the Eastern Ghats. Taking into account climate change, which is likely to have eliminated areas of Moist Deciduous woodland since the mid-Holocene, suggests we might seek *V. radiata* origins in some of the minor hill groups between the Godavari and Krishna rivers. In addition there are early finds in the Eastern Harappan zone near the upper Ganges, by the mid-3rd millennium BC. This suggests that there may have been an additional domestication of the mungbean deriving from the wild populations of the western Himalayan foothills.

Post-domestication seed enlargement in mungbean and urd

One of the common characteristics of domesticated seed crops is an increase in seed size over their wild progenitors (e.g. Schwanitz 1966; Hawkes 1983; Harlan 1992; 1995, 34). This is notably the case with pulses, including *Vigna* spp., based on comparisons between modern cultivated and wild populations (Smartt 1990, 168; Gopala Reddy and Vinayak 1990). Additional comparisons of seed size between modern populations were made as part of the present study, including a more limited available sample of the wild progenitors (Fig. 11A). These measurements confirm an earlier study by Miyazaki (1982, 5), who reported seed lengths of 3·5–6·2 mm for domesticated

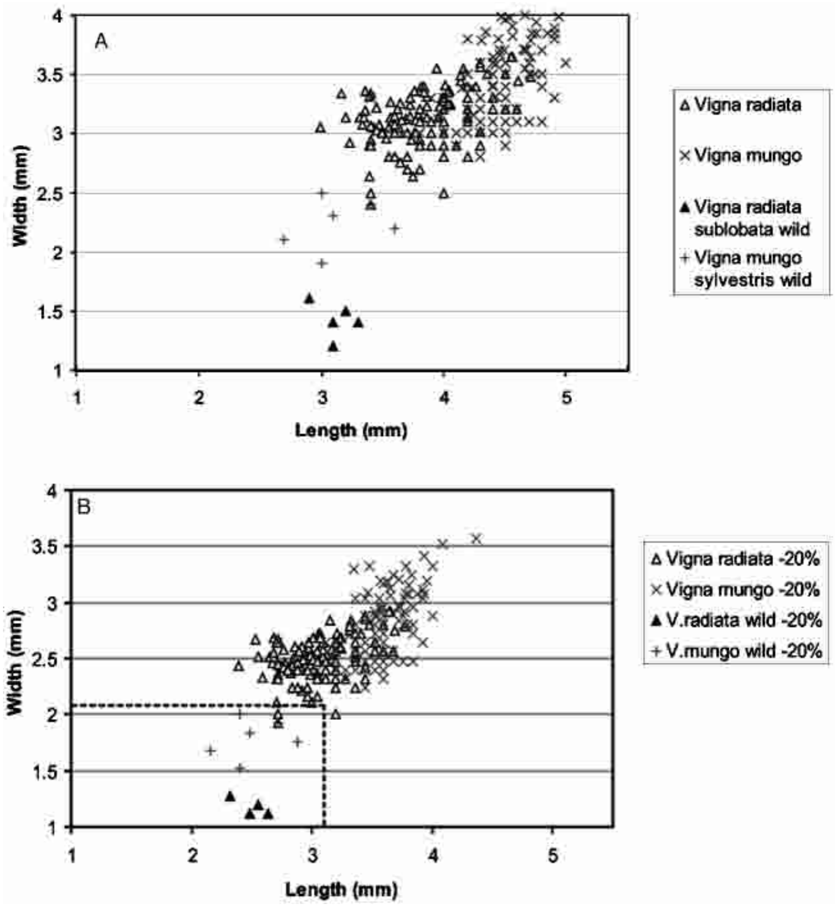

Figure 11 **Scatter-plot of measurements for modern domestic and wild *Vigna radiata* and *Vigna mungo* seeds. A. Modern reference seeds. B. Scatter plot adjusted to reflected of predicted shrinkage (−20%) from charring, with a dashed box around the area of wild seed measurements**

mungbean, and 2·6–3·3 mm for the wild form *V. radiata* subsp. *sublobata* (Miyazaki 1982, 9; also Subramanian 1983).

In order to compare the modern and archaeological material, however, it is necessary to make some estimate of the amount of size change (shrinkage) due to charring. Furnace charring experiments on pulses by Lone *et al.* (1993) reported an average shrinkage of 10·5%. Recent charring experiments comparing open fires with furnace conditions (Jupe 2003) suggest that shrinkage is hampered while the seed coat remains intact, which is often the case in furnace

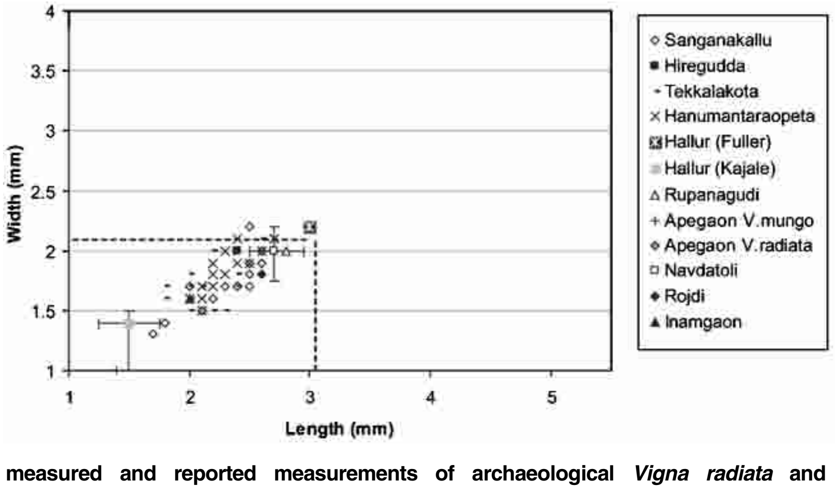

Figure 12 **Plot of measured and reported measurements of archaeological *Vigna radiata* and *Vigna mungo* from Prehistoric sites in South India**

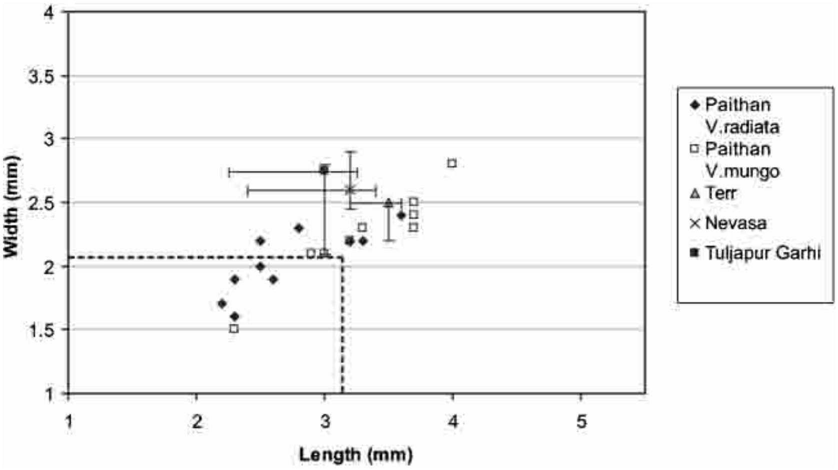

Figure 13 Plot of measured and reported measurements of archaeological *Vigna radiata* and *Vigna mungo* from Early Historic sites in South India

experiments. Open fire charring conditions indicate shrinkage of the order of 20% once the seed coat has charred away. Adjusting modern length and width by −20% provides a framework for considering measured archaeological specimens (Fig. 11B), in which exclusively wild types are expected to be beneath 3 mm length and 2 mm width.

Measured specimens from Southern Neolithic sites fall almost entirely within the size range represented by modern wild populations (Fig. 12). By contrast those from Early Historic to Early Medieval sites, including Paithan specimens measured by us, fall in the range of modern domesticated populations (Fig. 13). Taken together this suggests that early cultivars, which are likely to be domesticated in terms of seed dispersal, had not yet undergone evolutionary change towards larger seed sizes. Morphological domestication is best defined on the basis of loss of dormancy and non-dehiscent pods (see Zohary and Hopf 1973; 2000; Butler 1989). Specimens from the Southern Neolithic and Maharashtra, with the possible exception of those from the site of Hallur, occur in dry savannah environmental zones where the wild forms would not have occurred. This, together with co-occurrence with other likely cultivars and some definite introduced cultivars (wheat and barley), as well as high sample ubiquity, argues for the cultivation of *Vigna radiata* during the Neolithic (Fuller 2003b; Fuller *et al.* 2004). If it was being routinely harvested, either by pod-plucking or plant uprooting, and sown from stores, we would expect domesticated forms to have evolved with less dehiscent pods and loss of dormancy (following the experimental models of domestication of other species, *cf.* Ladizinksy 1987; Hillman and Davies 1990).

These archaeological data suggest that metrical criteria cannot be used to determine domesticated versus wild status. Instead, we would propose the broader term ‘primitive’ to apply to both early domesticated and wild forms in which seed size remains small, as opposed to ‘advanced’ or enlarged forms which represent a secondary improvement under cultivated conditions. It is clear that Early Historic samples from the peninsula fall clearly into this advanced size range, overlapping with that of modern cultivars. These data suggest on peninsular India selection for increasing pulse seed size was slight through the 2nd millennium BC but had occurred by the 1st millennium AD. The evidence from late Chalcolithic Tuljapur Garhi (late 2nd millennium BC to early 1st millennium BC), shows a wide size range from wild-type to domesticated-type, although the average falls in the latter range. This site, located further east in Maharashtra, away from the Western Ghats, might represent evidence for the actual process of size increase, suggesting that this occurred most markedly during the late 2nd millennium BC through the Iron Age.

These data raise the question of what change in the environmental conditions, most likely in terms of agricultural practices, selected for seed enlargement in these pulses. Contrary to conventional botanical assumptions (e.g. Harlan 1995, 22; Smith 1995, 18), it cannot be assumed that size increase is part of the initial domestication syndrome, and other explanations must be sought. Perhaps conscious selection is brought to bear by farmers (Heiser 1988, 79), or perhaps changes in agricultural techniques such as deeper tillage created a selective advantage for larger seeded genotypes. In this regard the Iron Age in

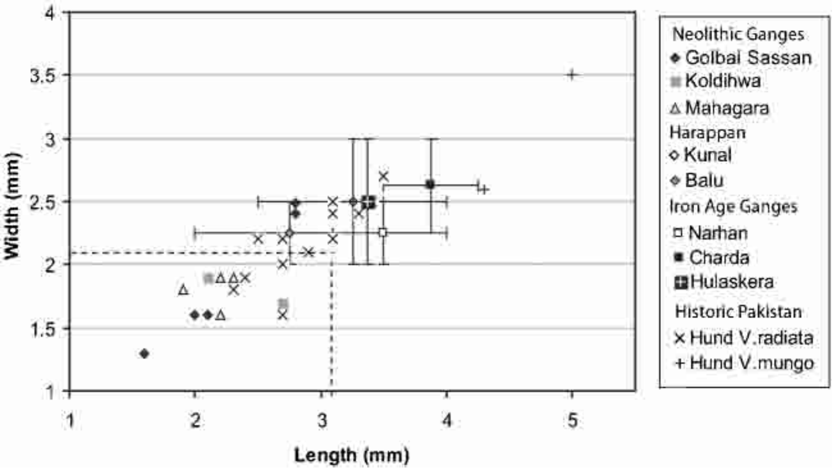

Figure 14 Scatter-plot of measured and reported measurements of archaeological *Vigna radiata* and *Vigna mungo* from sites in Northern India. Note seed size enlargement in Bronze Harappan sites with plough agriculture and in Iron Age Ganges sites

South India, and perhaps the later Chalcolithic were the periods when ard tillage began on the peninsula.

Measurements from northern India suggest a similar pattern in middle Ganges and Orissa, but suggest a contrast with early pulses from the north-west (Fig. 14). What can be seen in the plot is that Neolithic seeds fall largely in the expected primitive size range, while later sites such as late Chalcolithic Narhan and later Iron Age and Early Historic sites have large *Vigna* grains. Interestingly two early sites, Balu and Kunal from the later 3rd millennium BC also have large *Vigna* seeds. Both of these sites, however, are within the Eastern Harappan cultural zone, where we expect deep tillage with ards to have been the norm. This is based on the finds of ard marks sealed at the Kalibangan site (Lal 1971), and a model ard from Banawali (Allchin and Allchin 1997, 170), both sites in the region, as well as bovine osteological evidence from Harappa (Miller 2003). It might be suggested that in the Harappan zone enlarged seeds have already been selected for by tillage in the 3rd millennium, whereas further east this process did not occur until the late 2nd millennium BC. This of course raises the questions of whether pulses introduced into the middle Ganges zone, as might have been the case with *Vigna* spp., had diffused before the emergence of large-seeded forms, or had diffused from a non-Harappan zone, or else whether the absence of positive selection through tillage could have lead to a reversion to smaller seed size. Further research on the possible selective pressures and genetic architecture of size increase in legumes is needed.

Pathways to archaeological preservation: pulse crop processing

The importance of models of crop processing pathways, developed from ethnographic observations, is recognised as an important aid in archaeobotanical interpretation (e.g. Hillman 1981; 1984; Jones 1984; 1987; Hastorf 1988; Reddy 2003; Harvey and Fuller 2005). While most studies have focused on cereal species, models are also required for pulses, which usually require some combination of threshing and winnowing processes. A working model for the processing pathways of Indian pulses is developed from a combination of brief descriptions in the literature, a few observations in the field by the authors, and morphological observations of the taxa involved (Table 5). Pulses, in particular vetches, peas, lentils and grasspeas, were included in the ethnoarchaeological study of Jones (1984; 1987) and work by Butler (1992; Butler *et al.* 1999). These studies indicate that *Vicia* and *Lathyrus* can be treated as basically similar to free-threshing cereals, which is also the case for other pulses of South-west Asian origin. A perusal of descriptions of harvesting and processing of South Asian pulse crops, however, indicates that this is not the case for all pulses (Watt 1889–93; Kachroo and Arif 1970; van der Maeson and Somaatmadja 1989; Weber 1991, 98–9; Westphal 1974). Rather, there are two categories, one which is free-threshing, and one that can be termed 'pod-threshing' as it requires additional pounding and winnowing much as glume wheats and hulled-millets do. However, as ethnographic processing of *Vicia*/*Lathyrus* reveals there is in fact a spectrum of threshability; many pods do not shatter during the

Table 5 A general model for pulse crop-processing

Modelprocess	variant	pulse taxa	effects	remarks
Havesting	uprooting	*Macrotyloma* (Watts 1908, 506); *Vigna radiata* (Watts 1908, 200)	incorporates weeds, especially climbers	
	cutting near base	*Lablab* (Watts 1908: 510); *Cajanus* (Westphal 1974; Van der Maeson 1989); *V. aconitifolia* (Vcan Oerrs 1989a); *Macrotyloma* (Jansen 1989)	incorporates weeds, especially climbers	
	plucking pods	*Lablab* (Shrvashankar & Kulkarni 1989; Duke 1991); *Vigna radiata* (Watts 1908, 200; Weber 1991, 98)	selects against weeds	more likely in Neolithic due to uneven ripening. skip down to coarse sieving or pounding and rewinnowing
Threshing	free-threshing	*Lablab, Vigna*	frees pulses from pods and plants	some pods will not shatter, threshing of the by-product can be repeated one or more times to increase seed recovery
	pod-threshing	*Macrotyloma, Cajanus,*	separates pods from plant	in Cajanus leaves are stripped or separated by simple shaking
Winnowing and Raking	free-threshing types	*Lablab, Vigna*	separates light material including pod fragments: product includes pulse seeds, large and small weeds, pod pedicils(?)	skip pounding and rewinnowing (pod-threshing) step. By product may be used as fodder. If some pods are insuffieciently broken, threshing may be repeated.
	pod-threshing types	*Macrotyloma, Cajanus,*	separates light material; product includes pods, large heavy weeds, headed weeds, stem pieces. Pulse seeds from broken pods may enter by-product	By-product may be used as fodder. Mature seeds may enter dung. Possible stored as pods after this step. Possibly stored as pods after this step
Coarse sieving	free-threshing types	*Lablab, Vigna*	removes plants stalk parts, weed heads. Will lose some pulse seeds, especially unshattered pods.	By-product may be used as fodder. Mature seeds may enter dung.
	pod-threshing types	*Macrotyloma, Cajanus*, some *Lablab*(?)	removes small and large weed seeds, pulse pods and weed heads remain (could be hand-picked)	
Fine Sieving	free-threshing types	*Lablab, Vigna*	removes remaining small weeds, chaff fragments Only weeds very similar in size and weight to pulse remain, possibly some pod pedicels (especially in *Vigna*). Will lose some small/immature pulse seeds.	store after this step as cleaned pulses: sieved again or hand-picked to remove remaining large weeds before cooking. Possible route to archaeological preservation.
	pod-threshing types	*Macrotyloma, Cajanus*		this step probably skipped
Pounding and rewinnowing	free-threshing types	this step unneccessary		
	pod-threshing types only	*Macrotyloma, Cajanus*, some *Lablab*(?)	removes pods, only some weed seeds or heads that are very close in size and wieght to pulse remain	possibly a daily routine processing: most likely route to archaeological preservation
Parching		parching or dry-rosting reported for *Vigna* spp., *M. uniflorum* (Watts 1908). *Lablab* reported to be 'dried' before storage (Shivashankar & Kulkarni 1989)	could lead to accidental charring and archaeological preservation	parched before grinding, or dry-roasting for consumption. Archaeological preservation route

Figure 15 ***Vigna mungo*** **harvested by uprooting, being threshed, Mayurbhanj District, Orissa. Photo: E. Harvey, 2003**

first threshing and therefore threshing is repeated for a second and third time (Butler *et al.* 1999). Nevertheless, pod-threshing and free-threshing types represent useful extremes for constructing some expectations concerning pulse processing. On the other hand, the distinction between free-threshing and pod-threshing pulse varieties will normally be taxonomically specific since it relates to the structure of pods and the seeds within them.

Prior to the threshing, another important division can be drawn between pulses that are uprooted or cut near the base (Fig. 15) and those from which pods are plucked individually (Fig. 16), often over a period of time for those plants with uneven ripening. Given that even ripening is likely to have evolved gradually under domestication, primitive cultivars are more likely to have been harvested over an extended period of time by the plucking method. When individual pods are picked, weeds are selected against in the first step and therefore never enter the archaeological record (as in hand picking cereal ears, *cf.* Hillman 1981). Although these different methods are expected to have an important effect on weed assemblage formation, they cannot be seen as inherent to a particular taxon (except for those with uneven ripening), and are thus subject to cultural choice. Crops that are generally harvested near the ground may be heavily weed infested, especially as most of the legumes are of twining habit and may get tangled up with other plant species. As Jansen (1989, 54)

Figure 16 ***Vigna uniguiculata*, which has been harvested by plucking pods, being pounded to free the seeds, Shimoga District, Karnataka. Photo: D. Fuller, 2000**

notes, *Macrotyloma* requires thorough winnowing and sieving due to a normally high weed content. In addition, since pod-threshing varieties require an additional pounding and winnowing step, especially to remove the pods, there is more opportunity to lose crop seeds with processing waste that might subsequently be burnt, and we might therefore predict that these types will tend to be more frequently preserved archaeologically. This observation may help to explain some of the discrepancies between the quantities of *Macrotyloma* and *Vigna* encountered in most samples from South Indian Neolithic sites, in which *Vigna* (which is free-threshing) is much less frequent (Fuller *et al.* 2004).

Lablab purpureus probably includes both pod-threshing and free-threshing varieties, although field observations are needed. The most advanced cultivars of this species in India are of subsp. *bengalensis* which is presumably free-threshing. Nevertheless, *Lablab* is reported to require intensive winnowing to remove weed contaminants (Duke 1981, 105). On the other hand, the primitive subspecies *uncinatus* has small, flattish pods of roughly similar shape to those of *Macrotyloma.* It is likely that such pods will survive initial threshing intact. It is presumably this early variety that was first introduced to India, and indeed *Lablab* seeds are highly numerous in samples from the Neolithic site of Sanganakallu (Fuller 1999; Fuller *et al.* 2004) and Inamgaon (Kajale 1988b), as we might expect if a pod-threshing variety was involved. The widespread subsp. *purpureus* may also be pod-threshing but ethnographic field observations are needed.

Sieving appears to be optional in Indian pulse processing. While coarse sieving may be used to separate unbroken pods, and large unwanted contaminants from freed seeds, this is likely to prove useful only if harvesting is by uprooting or basal cutting. Fine sieving, on the other hand, may serve to remove small weed seed contaminants that are too heavy to be winnowed out. The absence of sieving is apparent in ethnographic examples of millet processing in India (Reddy 2003) and rice processing in Thailand (Thompson 1996), and consequently the absence of sieving may be part of the cultural tradition in the regions, which contrasts with processing traditions observed in the Mediterranean (e.g. Jones 1984; Butler 1992). We have not observed sieving used in pulse processing while carrying our archaeological fieldwork in various parts of India. These discrepancies highlight the need for more detailed observations on processing of pulses, which variations are strongly correlated with species or morphology and which appear more flexible, i.e. showing variation between cultural traditions. It is also important that quantitative data is gathered on Indian pulse processing product and by-product assemblages in order to assess the representativeness of quantified archaeobotanical remains.

Although more detailed ethnographic data on pulse processing in India is needed, the general model suggested here provides a plausible framework with which to assess how pulses came to be preserved archaeologically. As with the millets and large cereals, the regular need for processing before and sometimes after storage creates opportunities for the accidental loss and charring of pulses. In addition, because processing by-products are often used as fodder, incidental inclusions of mature pulse seeds, which are essentially indigestible, may be preserved archaeologically when dung is burnt as a fuel — although there is no reason to believe that this was normally the case in the Neolithic of India from which our archaeological examples come (Fuller *et al.*

2001; Fuller 2003b, 353). Parching to prepare the pulses for consumption or to dry them for storage is also a normal practice for several taxa – and provides the possibility of accidental charring and archaeological preservation. Interestingly, we have found no reports for parching of *Cajanus* which is extremely rare in the archaeological record in contrast to other South Asian pulses that are routinely dry-roasted.

Pulses in the South Asian record: multiple centres and dispersals

Despite the difficulty of inferring domestication, archaeobotanical evidence attests to the widespread cultivation of pulses in Neolithic and Chalcolithic South Asia from at least the early to mid-3rd millennium BC. Table 4 summarises the presence of indigenous and introduced pulses from the South Asian archaeobotanical record, with sites plotted in Fig. 1. There are clearly regional differences in the frequency of particular pulses, as well as pulses in total. While explaining these patterns remains a challenge, it can be suggested that environmental conditions, differences in processing and cultural practices of preparation and consumption, all contributed to inter-regional differences.

The Vicieae pulses of South-west Asian origin appear to have spread into India more or less as a package with wheat and barley. In virtually every find of these species they co-occur with wheat, barley and one or more of the other South-west Asian pulses. Of these taxa *Cicer arientinum* is relatively rare, although this could be due to taphonomic masking, as open-air charring experiments have shown it to be significantly less often preserved than lentils or peas (Jupe 2003). It is clear that all of these species were present in the Indus Valley region by the time of the Mature Harappan period (2600–2000 BC). What is obscure, however, is whether these pulses formed part of the initial agricultural package with wheat and barley which became established in Baluchistan before 6000 BC, as represented by the evidence from Mehrgarh. Early Harappan levels of Kunal, near the Indo-Gangetic divide, have provided finds of all of the winter pulses before 2500 BC (Saraswat and Pokharia 2003). It is during the Mature and Late Harappan periods when, together with wheat and barley, these winter pulses were adopted across much of monsoonal India as part of a two-season cropping system.

It seems more likely that they were already well established in the Indus valley prior to this, although the earliest finds are 4th millennium. This includes finds of lentils from Miri Qalat in the early 4th millennium (Tengberg 1999), and the Bannu Basin (Thomas 1999). From a similar date are possible peas from Nal (Benecke and Neef 2005). The absence of these species from Mehrgarh is readily explained by the lack of flotation samples and the emphasis on plant impressions (in mud-brick) (Constantini 1983). Large studies of impressions in other world regions virtually never include pulses (e.g. Jessen and Helbaek 1944; Helbaek 1952; 1959; Magid 1989; Stemler 1990; Zach and Klee 2003). Impressions normally reflect the use of crop-processing waste, as a tempering material for clays. Chaff-producing taxa, especially cereals, are favoured, while pulses are predictably absent. The absence of evidence from Mehrgarh does not therefore constitute strong evidence for the absence of these pulses. Whether or not pulses were cultivated alongside wheat and barley from the foundational phase of Mehrgarh is of significance in relation to arguments about whether or not plant cultivation began in Baluchistan in parallel to that in the Near East or was introduced by diffusion/migration from the Near East (*cf.* Fuller 2003b; 2003c; Bellwood 2005). Arguments in favour of Baluchistan as an independent zone of winter crop domestication have overlooked the likely significance of pulses alongside cereals in early agriculture (such as, Possehl 1999, 405–6; 2002, 23–4; Chakrabarti 1999, 117–22). It is plausible that winter pulses came to South Asia as part of a winter crop package originating in the Near East.

Further away from the Indus valley, these crops did not become established. They are largely absent from Southern Neolithic sites and entirely absent so far from Orissa. By contrast they became established by *c.* 1700 BC in the northern peninsula, although on current evidence *Cicer* may have arrived later than *Lens*, *Pisum* and *Lathyrus*. While some of these pulses have been recovered from sites on the Saurashtra peninsula, such as Rojdi and Babar Kot, in these regions they appear to have been adopted largely independently of wheat and barley agriculture. Thus, while for much of India the winter pulses can be thought of as part of a package with wheat and barley, in a few regions, including Saurashtra and South India, this association appears to have broken down. It is worth noting that both of these regions represent areas where independent plant domestication can be argued, as opposed to many other parts of the subcontinent (Fuller 2003b; 2003c). In the case of South India it can be suggested that wheat and barley were preferentially adopted for inclusion in particular foods (or drinks), while winter pulses were less attractive (Fuller 2005).

Patterns of dispersal for the pulses of Indian origin are less clear although they were established by the time the South-west Asian pulses were present suggesting that native systems of pulse agriculture and diet existed. These native pulses were present in the whole range of agricultural systems, including those relying on wheat and barley, millets or rice. In the case of *Macrotyloma*, regions which have produced probable early finds, dating back to *c.* 2500–2200 BC, which could represent zones of domestication, include Southern India, and the middle to upper Ganges valley. Much of central India (Madhya Pradesh), however, remains largely unsampled. For *Vigna radiata* and *V. mungo*, the archaeological reports fit with a model of domestication in separate regions. For *V. radiata* two domestications can be suggested on the basis of archaeobotany, one associated with the Southern Neolithic and the other with the upper Ganges basin, which corresponds fairly closely to its western Himalayan wild distribution. Early Harappan Kunal, and Harappan Mitathal and Balu have produced *V. radiata*, indicating its establishment by the 3rd millennium BC. As discussed above metrical data suggest that these were varieties with enlarged seeds, suggesting the initial cultivation was earlier still. By contrast, in the well-sampled sites of the Neolithic Ganges (such as Mahagara, Koldihwa and Senuwar), it occurs only in contexts from *c.* 2000 BC and later. Similarly, it appears only later in the 2nd millennium on the northern Peninsula and in Saurashtra, as at Rojdi and Inamgaon.

V. mungo by contrast is present much earlier in Saurashtra and at Kaothe in Maharashtra. It is later in the middle and upper Ganges valley, Maharashtra, and is by and large absent from the Southern Neolithic.

Finds of *V. aconitifolia* are all later suggesting that this was a secondary domesticate, perhaps originating from the Ganges basin in the late 2nd millennium BC, that became widely established by the early historic period (early 1st millennium AD).

Botanical evidence is much clearer about the region of pigeonpea (*Cajanus cajan*) origins, although the archaeological evidence is more sparse. Published evidence had suggested that *Cajanus cajan* must have been domesticated by c. 1500 BC by which time it begins to be found on sites outside its wild range on the eastern peninsula. The new find, reported in this paper, from Gopalpur in Orissa from a Late Neolithic/Early Chalcolithic level, suggests that it was being cultivated in its general region of origin by *c.* 1500 BC. Of interest is the apparent absence of the species from Gangetic agriculture until the historic period.

The two pulses of African origin (*Lablab purpureus* and *Vigna unguiculata*) had both become widespread by *c.* 1500 BC. The earliest evidence is that of *Lablab* from the upper Ganges region where it was present in levels reported to date before 2000 BC. The evidence from the South dates to Neolithic Phase 3, 1800–1400 BC, with direct dates on *Lablab* dating back *c.* 1500 BC (Table 3). Finds from Maharashtra, as at Inamgaon, fit into this same time horizon. How *Lablab* had come to India and dispersed to these areas remains unknown, although it needs to be considered in the context of other crops introduced from Africa in this same time horizon (Fuller 2003a). Evidence from the mid-2nd millennium BC indicates that this species had become widespread in regions with millet or rice cultivation. The two reports of *V. unguiculata* are also from such sites.

One pattern which is striking in the archaeological record of pulses in South Asia, is their higher ubiquity and relative frequencies on peninsular sites, as opposed to those in northern or north-western India. As we expect pulse preservation to be the result of charring during or after some of the crop processing stages, this inter-regional contrast might be attributable to distinctive cultural practices with regards to processing pulses. In general we would predict pod-threshing types to have more inadvertent loss as many seeds are retained in the pod until a final pounding. Thus we might expect free-threshing types to be underrepresented. In western and northern India, however, pod-threshing types are also less frequent than they are in South or East India. This suggests that some other cultural practice led more often to charring and preservation of pulses, of both pod-threshing and free-threshing varieties, on the Indian peninsula (including Orissa). Parching/dry-roasting before the production of pulse flour could be such a cause. This might explain the enigmatic contrast provided by the evidence from the Saurashtra peninsula in which sampled sites have been particularly poor in pulses. While a few finds indicate that some pulses were grown here, the dearth of finds suggests either that pulses were of minor agricultural and dietary significance within this cultural area (the Sorath Harappan culture in the terminology of Possehl 2002) or else that they were processed and consumed in a different, less easily preserved, manner, perhaps as green pod vegetables or sprouted seed. By contrast, parching or dry-roasting as a precursor to preparation of pulse flours might be a regionally distinct culinary tradition that led to higher levels of pulse charring in peninsular India.

Conclusion

Archaeobotanical evidence allows for the identification of the whole range of pulses in India. Unfortunately actual indicators of the domestication process are not yet known. It appears that post-domestication size change, at least for *Vigna radiata*, was considerably delayed from the earliest cultivation by perhaps 1500–2000 years. Early domesticated pulses can be considered 'primitive' in the sense that they are indistinguishable in size from their wild progenitors. This may have implications for the nature of early pulse fields, which presumably did not have the kinds of conditions that would be expected to select for larger seeds. The role that hand-picking of pods may have played in delaying selection for some domestication traits deserves research, although as we have suggested a key factor may be tillage methods, with the presence of deep tillage such as that by animal-drawn ards suggested to be a key factor in selecting for larger seed size. Ladizinsky (1987) argues that selection of 'domesticated' pulses, in terms of pod indehisence, may have needed to have occurred before cultivation was feasible (a hypothesis not accepted by Zohary and Hopf 1973; 2000). The implication of Ladizinsky's observations on wild lentils, in terms of seed production, yield and dispersal, is that they differ from wild cereals, and might therefore need to be considered through a different model of domestication. The evidence for a delay in seed size increase, as seen in Indian *Vigna* spp., similarly suggests a contrast with the processes of cereal domestication. Data from cereal grains in the Near East suggest that grain-size increase may have occurred under primitive cultivation and preceded change to tough rachis cereals (Willcox 2004). Pulses might therefore represent a very different evolutionary trajectory in terms of the relative ordering of different aspects of the domestication syndrome.

On most sites that have been sampled systematically in peninsular India (including Maharashtra, Orissa, Karnataka, and Andhra Pradesh), pulses are amongst the more frequent find categories, which seems to be attributable to some distinctive aspect of pulse use. We have suggested that this may result from large scale use of pulse flours in Indian Peninsular culinary traditions, which remain important to the present day, as dry-roasting prior to flour grinding would have provided a recurrent route to accidental carbonisation. While agriculture is often discussed in terms of staple cereals, pulses clearly play an important role in modern and ancient agriculture in India. Archaeobotanical research promises to elucidate this role and the part played by pulses in the origins of indigenous agricultural systems and spread of crop packages originating in other regions.

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