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Early plant domestications in southern India: some preliminary archaeobotanical results

Abstract Analysis of flotation samples from twelve sites in Karnataka and Andhra Pradesh (south India) provides clear evidence for the predominant subsistence plants of the Neolithic period (2,800–1,200 cal B.C.). This evidence indicates that the likely staples were two pulses (*Vigna radiata* and *Macrotyloma uniflorum*) and two millet-grasses (*Brachiaria ramosa* and *Setaria verticillata*) which were indigenous to the Indian peninsula. At some sites there is evidence for limited cultivation of wheats (*Triticum diococcum, Triticum durum/aestivum*) and barley (*Hordeum vulgare*), and a few crops that originated in Africa, including hyacinth bean (*Lablab purpureus*), pearl millet (*Pennisetum glaucum*) and finger millet (*Eleusine coracana*). In addition there is evidence for cotton (*Gossypium* sp.), and linseed (*Linum* sp.), as well as gathered fruits of *Ziziphus* and two Cucurbitaceae. This evidence suggests that the earliest agriculture in south India, dating to the third millennium B.C., was based on plants domesticated in the region, and that subsequently from the late 3rd millennium B.C. through the 2nd millennium additional crops from other regions were adopted into the subsistence system.

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Introduction

The origins of agriculture in south India have been obscure. Despite the fact that a large number of crops are thought to have originated in south Asia (Zeven and de Wet 1982; Vavilov 1992), there has been little problem-oriented research into the processes by which these plants were brought into cultivation. Vavilov's (1992) Indian Centre of Origin has remained poorly researched, and general syntheses suggest that local plants were brought into domestication only after cultivation was established based on introduced domesticates (for example Hutchinson 1976; Harlan 1992; Willcox 1992). Some other authors, however, have maintained that native taxa may have been domesticated before the introduction of crops from other regions (Vishnu-Mittre 1989; Mehra 1997, 1999; Fuller 2002). In this paper, we report results from a study of archaeobotanical assemblages from 12 sites from the Southern Neolithic (2,800–1,200 cal B.C.) and discuss their implications for the evolution of agriculture in south India.

Two lines of indirect evidence suggest that south India may have been a region where crops were domesticated. First, botanical evidence indicates that the wild progenitors of a number of small millet-grasses (Panicoid subtribe Seteriinae) and tropical pulses occur on the Indian peninsula (reviewed in Fuller 2002). Second, the Southern Neolithic culture (back to at least 2,800 cal B.C.), predates the early villages in Maharashtra, which lies to the north, by at least three to four centuries (Possehl and Rissman 1992; Devaraj et al. 1995; Korisettar et al. 2001a). Thus there is an apparent spatial separation be-
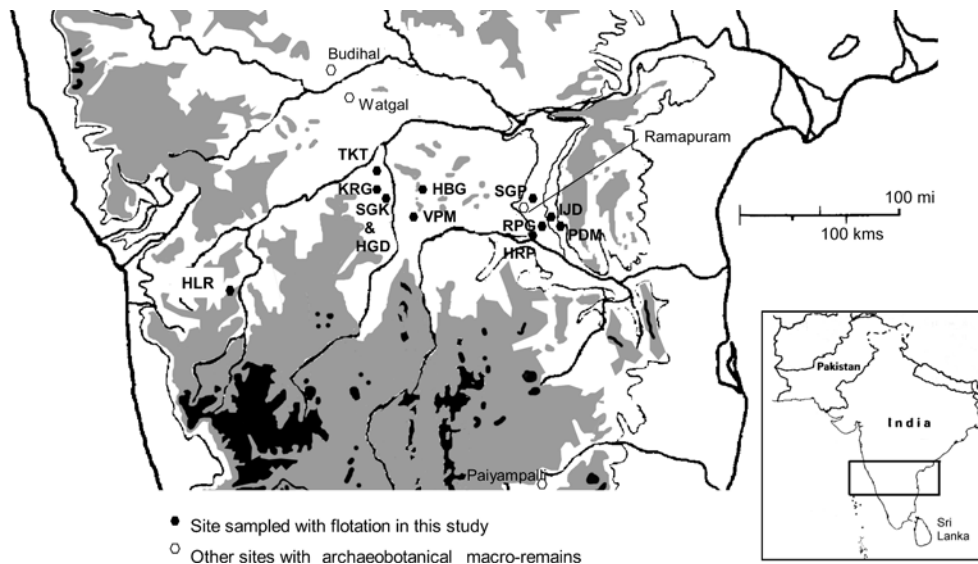
Fig. 1 Southern Neolithic sites with archaeobotanical evidence. Floatation samples in this study were collected from sites indicated by three letter abbreviations. Other important southern Neolithic sites with published archaeobotanical evidence are indicated by *open symbols* and *full names*. Abbreviations as follows: Hallur (HLR), Tekkalakota (TKT), Kurugodu (KRG), Sanganakallu (SGK), Hiregudda (HRG), Hattibelagallu (HBG), Velpumadugu (VPM), Singanapalle (SGP), Injedu (IJD), Rupangudi (RPG), Peddamudiyam (PDM), Hanumantaraopeta (HRP). Elevations indcated: 300 m contour (*line*), 600 m contour (*grey*), 900 m contour (*black*)

tween the Southern Neolithic and the already agricultural societies of the greater Indus valley (Meadow 1996, 1998). It is generally assumed that the intervening regions (including Maharashtra) would still have been inhabited by hunter-gatherers or perhaps herder-gatherers into the late 3rd millennium B.C. (cf. Dhavalikar 1994; Shinde 1994; Allchin and Allchin 1982), while south India was Neolithic, including at least domesticated fauna and probably cultivation (Allchin 1963). The intention of the present study was to test the hypothesis that some indigenous millets and pulses may have been domesticated independently in south India.

The Southern Neolithic, or Ash Mound Tradition, flourished from the beginning of the 3rd millennium B.C. until the transition to the Iron Age, ca. 1,200–1,000 B.C. (Allchin and Allchin 1982; Korisettar et al. 2001a). In the present study, samples were collected at sites representing three of these regional variants of this culture (Fig. 1): seven sites in the central region in the Bellary District and part of adjacent Anantapur district; the site of Hallur on the upper Tungabhadra river to the west; and five sites in the Kunderu river valley to the east in northern Cuddapah District and southern Kurnool District (Korisettar et al. 2001b; Fuller et al. 2001). A distinctive aspect of the central region of the culture is the ash mound sites that consist of large, heaped accumulations of cattle dung which have been episodically burnt (Allchin 1963; Paddayya 1973, 1992), and are thought to represent seasonal pastoralist camps (Allchin 1963, 1997; Korisettar et al. 2001a; cf. Paddayya 1992). More permanent settlements in this region are usually located on the tops and terraces of castellated granite outcrops, such as Sanganakallu and Tekkalakota. In both of the other regions, ash mound sites

are absent and settlement sites were located on or adjacent to alluvial plains.

The three regions studied can also be distinguished on the basis of geology and potential vegetation (Puri et al. 1983; Saldanha 1984). The Bellary District and Northwestern Anantapur District, where seven sites were sampled, fall in the *Acacia-Albizia amara* tropical thorn forest zone, termed "dry evergreen" by Puri et al. (1983). Today this zone is largely cultivated, or else grassland, with patches of *Acacia* and *Albizia* scrub, and managed *Ziziphus mauritania* trees. While this vegetation is maintained by human interference, it is unlikely that this region, the driest of the interior peninsula (Meher-Homji 1967), ever supported true woodland even under the somewhat wetter conditions of the 3rd millennium B.C. (cf. Caratini et al. 1994; Fuller 1999; Fuller and Madella 2001). Hallur lies in the region of the Dharwar greenstone belts, forming low north-south hills and predominantly reddish-brown sandy soils. Modern potential vegetation in the region is considered to be dry deciduous forest dominated by *Tectona grandis*, *Anogeissus latifolia* and *Terminalia tomentosa*. In the immediate vicinity of the site and the modern village of the Hallur, however, forests are absent as the area is under cultivation and grazing. In this denuded environment thorny scrub occurs on steeper slopes and in gullies, including much *Acacia* spp. The third group of sites, located in the Kunderu river valley of Cuddapah district and southern Kurnool district, is dominated by black, clay-rich *regur* soils developed from the shales and limestones of the Cuddapah Supergroup (Ramam and Murty 1997). It is believed that this region could support dry deciduous forests and woodland of the *Anogeissus latifolia-Hardwickia bipinata* type, although

much of the region is now deforested and under cultivation. East of the Kunderu river valley rise the Nallamalai Hills, which are cloaked in a denser dry deciduous forest including *Terminalia* and numerous moist deciduous elements such as *Tectona grandis* and *Piper nigrum*.

Materials and methods

Southern Neolithic sites across the three regions outlined above were sampled stratigraphically for archaeobotanical remains (see also Korisettar et al. 2001b). Plant remains were collected from bulk sediment samples from Neolithic sites and separated by means of simple bucket flotation (like that of Helbaek 1969), using locally available water sources. Sediment was collected in approximately 20 l bags for flotation and at many sites multiple 20 l bags were collected from each stratigraphic unit to allow checking between samples. At most sites, layers were sampled from more than one sampling locus. Flots were collected on 0.5 mm mesh, and all water was pre-filtered to remove potential contaminants. The remains identified and recorded in this study were preserved by charring, and occasional uncharred seeds were considered modern intrusives. For habitation fill layers this method allowed the recovery of charred macro-remains, including wood charcoal, charred parenchyma tissue fragments, and seeds/fruits. Flotation was not successful, however, in the case of the ashy, dung-derived sediments from ash mounds, because the dung-derived sediments floated very nearly in their entirety and the quantity of charcoal was minute and did not repay the time-consuming process of separating it from the sediment by hand. Four sites yielded the most extensive and important datasets: Hallur (HLR), Sanganakallu (SGK), Tekkalakota (TKT), and Hanumantaraopeta (HRP).

All the material came from archaeological levels that can be referred to Phases II and III in the Southern Neolithic chronology of Allchin and Allchin (1982). These periods are equivalent to the better-dated phases from Watgal (Devaraj et al. 1995), IIB (2,300–1,800 cal B.C.) and III (post-1,800 cal B.C., ending by 1,200–1,000 cal B.C.).

Seeds/fruits, parenchyma fragments and wood charcoal were separated, and the seeds/fruits were further examined and sorted into categories of distinctive morphological types. These morphotypes were then identified taxonomically to varying levels of resolution on the basis of comparison with modern reference material whenever possible, as well as by comparison to published seed illustrations and descriptions. The bulk of seed/fruit material was found to consist of Panicoid grass caryopses, that is, 'millets', and leguminous seeds (pulses). Given that these two categories, millets and pulses, were also likely to have been staple foodstuffs, following the common cereal-pulse pattern of many agricultural systems, more detailed work on identification was focused upon these taxa. In addition, some other cereals, a few miscellaneous crops, and some probable weeds could be identified. Nomenclature generally follows that of the Madras Presidency Flora (Fischer 1928; Gamble 1935), but for a few cultivars taxonomic revisions are indicated below.

Results

The same group of crops dominated the sorted samples across most of the sites, including *Macrotyloma uniflorum, Vigna radiata, Brachiaria ramosa,* and *Setaria verticillata* (Tables 1–3). The widespread importance of these plants across the whole region is indicated by their high ubiquity (presence) across the sampled sites (Fig. 2). In addition, unidentified parenchyma fragments were frequent. *Triticum* spp and *Hordeum vulgare* were also

fairly ubiquitous but much less frequent in individual samples and absent from several sites. Other potential food plants were present but much less ubiquitous, although certain species had high ubiquities at individual sites, such as *Lablab purpureus* at SGK and *Oryza* cf. *sativa* at HLR.

The consistent range of taxa present in the samples implies that they derive from similar formation processes, which can be inferred to have been the charred waste of routine crop-processing. Derivation from dung can be excluded as a major source of remains due to the extremely limited range of savanna grasses and tropical shrubs that were found. The consistent presence of *B. ramosa* and *S. verticillata* types, both of which are generally rare and localized within south India, in contrast to the absence of the more widespread and common savanna grasses indicates that the remains which were found are not taxa regularly eaten by grazing animals (cf. Whyte 1964; Singh 1988). The generally low diversity of potential weed taxa and the occurrence of seeds of similar size to the millets, and from families known to include Indian millet weeds (such as Aizooaceae, Chenopodiaceae) suggests that the millets derive from the by-products of the final de-husking and winnowing process, when compared with the ethnographic examples of Reddy (1994). The rare occurrence of millet chaff remains is presumed to be due to differential destruction in charring. Although the relatively small sample sizes may account for some absences, we would argue that wheat and barley were not staple grains, since their lower presence contrasts with their regular occurrence on sites in regions where they were staple grains, such as in the Near East and Europe, or the Indus Valley (see Fuller and Madella 2001; Weber 1999) and the northern Indian peninsula (see Kajale 1988; Fuller 2002). Given that there are likely species-specific biases in representation due to differential seed production and loss during processing, taxa are quantified independently in two figures, which therefore show correlated trends between taxa while avoiding the potential biases of species-specific effects on relative frequencies.

The present data provide evidence for the staple cereal and pulse foods. Although there is no definitive morphological evidence for domestication of the native taxa, other lines of evidence suggest that some or all of these taxa were cultivated. First, plants are present which must have been introduced to south India as domesticates as they are non-native, for example *Triticum* spp. and *Hordeum vulgare*. The presence of native species outside their present wild habitats, such as *Vigna radiata* and *Cajanus* cf. *cajan* at sites in the Bellary district, also suggests that these taxa were introduced and cultivated, since the distribution of vegetation types during the 3rd and 2nd millennia B.C. was only marginally different from that of today, at least in terms of where these wild pulse progenitors would have grown (cf. Caratini et al. 1994; Fuller 1999; Fuller and Madella 2001). For species potentially native throughout the southern Deccan, these are likely to have been staple food grains because they fre-

118

Fig. 2 Ubiquities
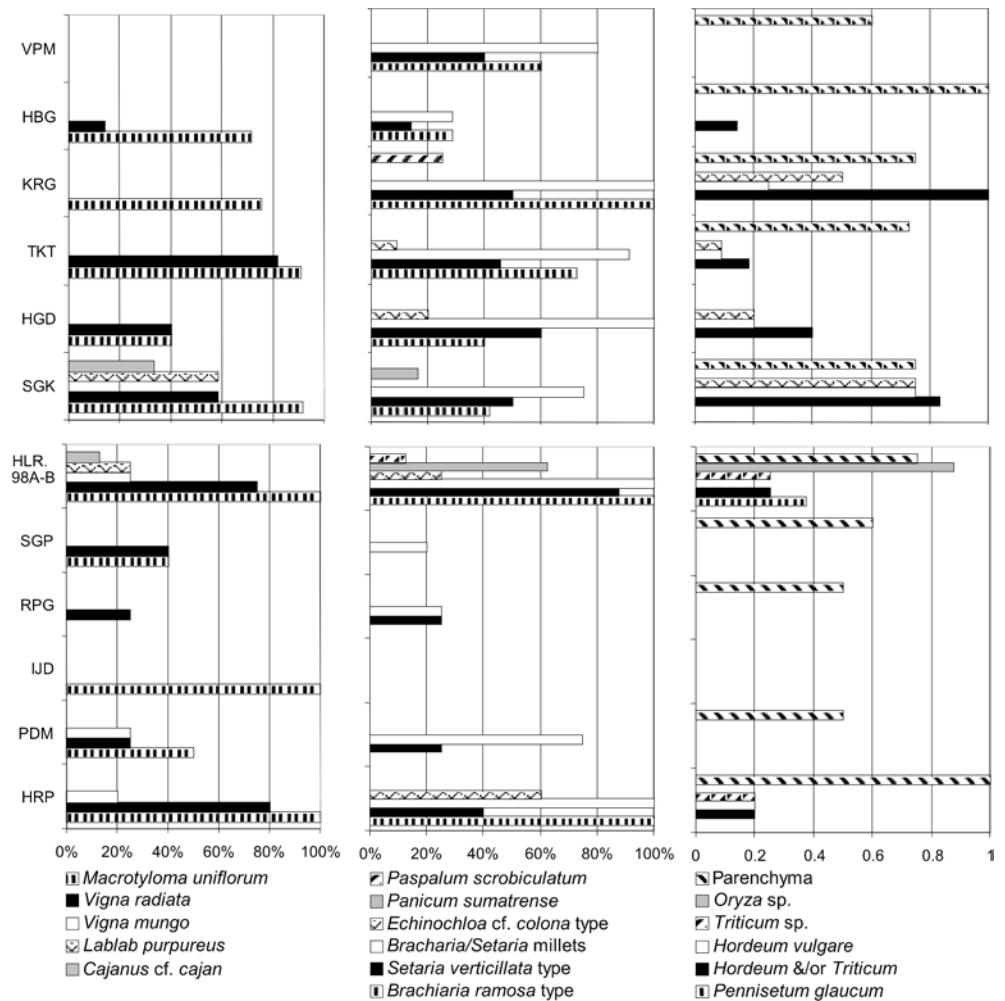
quently occur in samples (Fig. 2). The fact that they co-occur with taxa that must have been cultivated suggests that these native millet-grasses were also cultivated. In addition, the overall diversity of seed taxa encountered recurrently (that is with high ubiquity) is much lower than we would expect for hunter-gatherers with a broad spectrum diet (cf. Keeley 1992, 1995).

In the sections below, the main food crop taxa are discussed, together with identification criteria and background information for the probable crop taxa identified in the present study.

Vigna radiata (L.) Wilzcek and V. mungo (L.) Hepper

Three *Vigna* spp. in the subgenus *Ceratotropis* are important in traditional south Asian agriculture and derive from wild populations in India (Smartt 1990; Lawn 1995). V. *radiata* (Green Gram, Mung) and *V. mungo* (black gram, Urid) are known to derive from different wild populations that were formerly lumped as *V. sublobata* but now called *V. mungo* var. *silvestris* and *V. radiata* var. *sublobata* (Smartt 1985b, 1990; Lawn 1995). Published studies of seed coat morphology hint at separate geo-

graphical origins for *V. radiata* and *V. mungo,* with wild populations examined in the northern Western Ghats in Maharashtra sharing the *V. mungo* pattern (Sharma et al. 1977), and some studied populations from the southwestern Western Ghats in Kerala sharing the *V. radiata* pattern (Ignacimuthu and Babu 1985).

V. radiata and *V. mungo* share a large number of characters in common and the size and general shape of their seeds overlap (contra Vishnu-Mittre 1961). 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 (see Fig. 3; Lukoki et al. 1980; Chandel et al. 1984). 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, 1988, 1989b), although there is some statistical overlap of outliers.

Several specimens also preserved traces of the characteristic testa pattern of *V. radiata*, with wavy rows of very long, thin rectangular cells. Only three probable

specimens of *V. mungo* were identified. The even smaller, wild *V. trilobata* has been identified from a few samples.

The predominating *Vigna radiata* seeds and cotyledons, although probably cultivated, may still have been morphologically close to their wild progenitors. They are small relative to modern examples, even taking into account shrinkage due to charring (1.7–2.7 mm L, 1.5–2.1 mm W). Correcting the archaeological *Vigna* specimens for 10 to 30% shrinkage puts them in the reported size range for the wild *V. radiata* spp. *sublobata* (cf. Miyazaki 1982; Fuller 1999). The reported size ranges of examples from other peninsular Neolithic/Chalcolithic sites also fall within this general range (Vishnu-Mittre 1961; Kajale 1979, 1988, 1989b; Weber 1991), while significantly larger *V. radiata* seeds, comparable to modern domesticated forms, are found in published reports from the end of the 2nd millennium and the 1st millennium B.C., for example at Tuljapur Garhi and Narhan as well as Early Historic Nevasa and Ter (Kajale 1975, 1977b, 1989b; Saraswat et al. 1994).

Macrotyloma uniflorum (Lam.) Verdc.

The pulse *Macrotyloma uniflorum* (horsegram, kulthi) is widely cultivated in India. The scientific name of this crop has been prone to confusion. It has most often been referred to in Indian floristics and archaeobotany as *Dolichos biflorus* (for example Roxburgh 1832; Hooker 1872–1897; Watt 1908; Gamble 1935; Vishnu-Mittre 1989; Kajale 1991; Saraswat 1992). Subsequent re-examination of Linnaeus' (1753) material indicates that his *D. biflorus* actually refers to a form of cowpea (the catjang cowpea), that is *Vigna unguiculata* (L.) Walp, a highly polymorphic species which had previously been split into numerous species including several Linnean *Dolichos* species (Verdcourt 1971; Westphal 1974, p 224; Marechal et al. 1978). As a result, *V. unguiculata* is the correct synonym for *D. biflorus* L., but not for the crop 'horse gram'. Recently this synonym has entered the archaeobotanical literature (Weber 1991; Reddy 1994; Devaraj et al. 1995; Kroll 1996, 1997, 1998). However, this is *not* the correct equation for the *D. biflorus* auct. pl. cited in archaeobotanical and agricultural literature.

M. uniflorum was the most ubiquitous species overall and on most individual sites. The seeds are roughly trapezoidal and flattish, with quite thin cotyledons (Fig. 3). The hilum is small and linear and located in a small depression on the seed's lateral margin. The length of archaeological specimens is usually 3–4 mm, width 2–2.6 mm, and thickness 1.4–2 mm. Little is known about wild progenitor populations of *M. uniflorum,* although they were probably native to the shrub-savanna or thorny vegetational groups of the Indian peninsula (cf. Jansen 1989). Thus the region covered in this study could be an area in which it was domesticated.
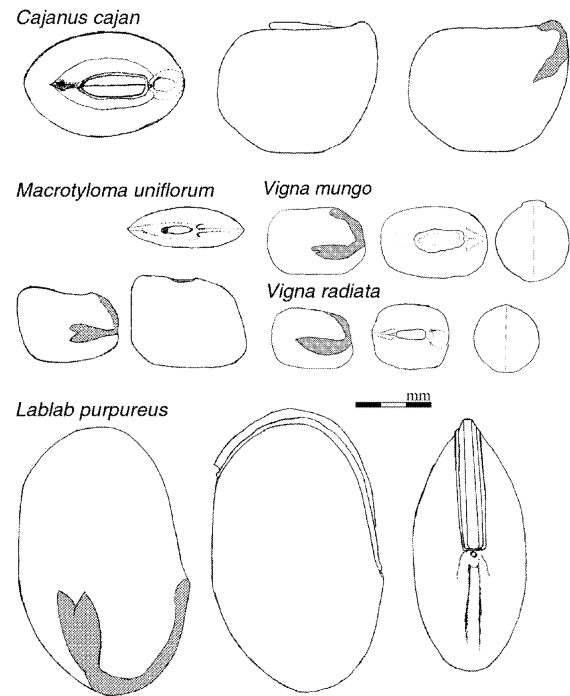

Fig. 3 Line drawings of pulse species found on southern Neolithic sites as part of the present study, showing basic characteristics of shape and proportions relied on for identification. Drawings based on modern reference material

Lablab purpureus (L.) Sweet

Lablab purpureus (hyacinth bean) occurs wild in East Africa (Verdcourt 1971; Smartt 1990), and thus probably reached India as a domesticate in antiquity. Large quantities of distinctive *L. purpureus* seeds, cotyledons and fragments were identified in the upper levels of SGK. Only three specimens were identified from HLR. No other definitive specimens were found from any other site, although fragments of a large-seeded pulse from HRP might be *L. purpureus.* Hyacinth bean seeds are generally reniform (kidney-shaped) and the lateral ends are generally more smoothly curved and cotyledons more convex than *Macrotyloma.* Round seeds occasionally occur, causing possible confusion with *Cajanus. L. purpureus* seeds were the largest pulse encountered (5–7.7 mm L, 3–4.7 mm W, 1–2 mm T). The most distinctive trait is a very long hilum, extending to nearly half the circumference of the grain, covered by a keeled strophiole. The hilum/strophiole, however, is rarely preserved, although even fragmentary preservation is highly distinctive and faint marks on the curved edge of the charred cotyledon often show where the hilum had been.

The evidence from the current study adds to a quantity of evidence for the presence of *L. purpureus* in India from at least the early 2nd millennium B.C. It had been previously reported in south India from HLR, TKT and Paiyampalli (Kajale 1991), and six sites to the north including Chalcolithic Maharashtra and Late Harappan eastern Punjab (see Fuller 2002). This species is the best-
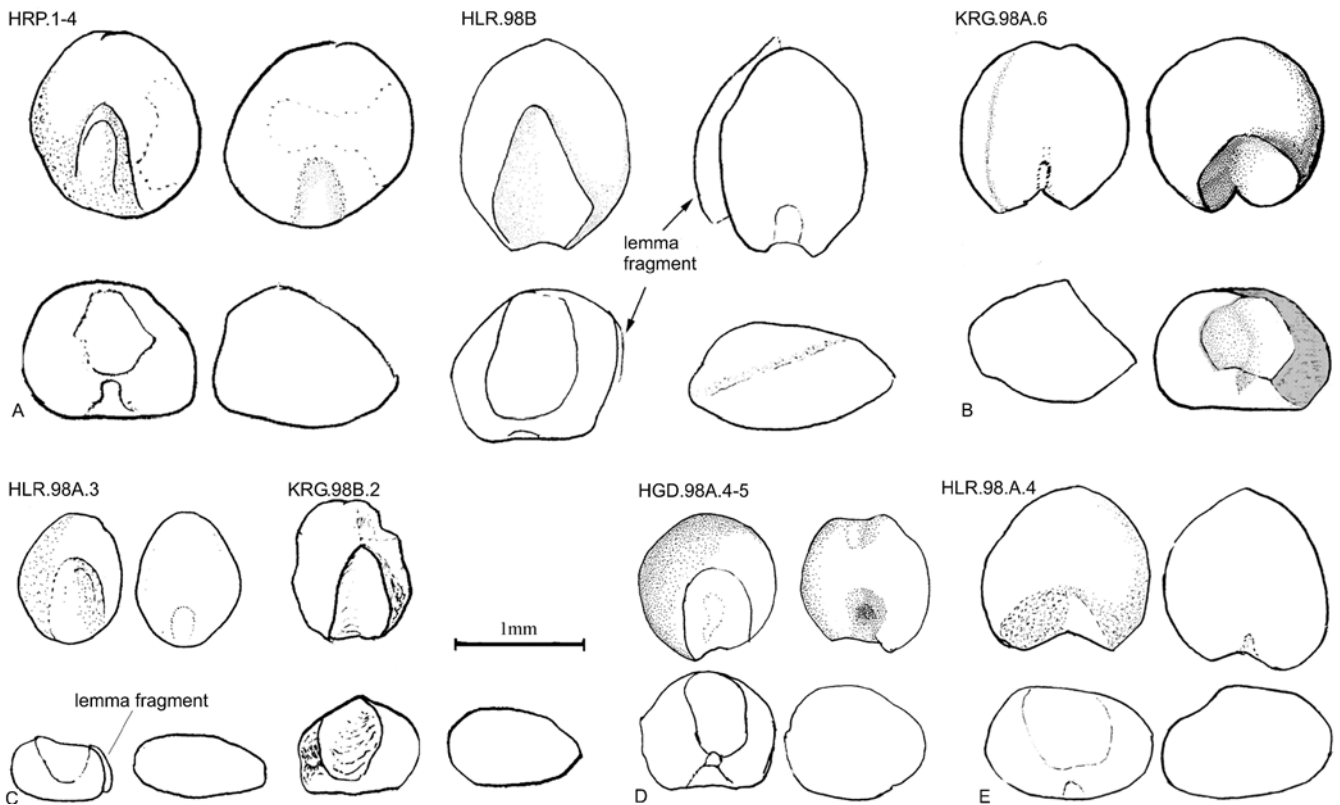
Fig. 4A–E Drawings of representative specimens of millet types. **A**: Examples of *Brachiaria ramosa* type from HRP.1–4 and HLR.98B; **B**: *Paspalum scrobiculatum* from KRG.98A.6; **C**: Ex-amples of *Setaria verticillata* type from HLR.98A.3 and KRG.98B.2; **D**: *Echinochloa colona* type from HGD.98A.4–5; **E**: *Panicum sumatrense, from* HLR.98A.4

documented crop of African origin in prehistoric south Asia.

Cajanus cf. *cajan* (L.) Millsp.

Cajanus cajan (pigeon pea, red gram), is native to the Indian peninsula, deriving from the species *C. cajanifolia* (Heines) van der Maeson of Orissa and Bastar (van der Maeson 1986, 1995). *C. cajanifolia* is quite rare today, although this is probably due in part to habitat loss. Other allied, erect species of wild *Cajanus* (formerly *Atylosia*) are restricted to the Western and Eastern Ghats and Sri Lanka (De 1974).

   In the present study, *Cajanus* sp. seeds and cotyledons were rare, but recovered from Period III at Sanganakallu, with a few possible specimens at Hallur. It is not possible to assign them with certainty to *C. cajan*. A complete specimen from Hallur may be of a wild species. The *Cajanus* specimens from layer 4 at Sanganakallu are more robust and thus similar to the crop (4.1–4.7 mm L, 3.6–4.4 mm W, 1.4–2 mm thick cotyledons). Given that there are no wild species of *Cajanus* that occur on the dry savanna plains of the central Deccan today (De 1974; van der Maeson 1986), it is safe to infer that the Sanganakallu specimens were cultivated.

Brachiaria ramosa (L.) Stapf. type

The predominant millet caryopses were ovate to round, each with a long and deep scutellum, as is found in the genera *Setaria, Echinochloa* and *Brachiaria* (Fig. 4). In almost all assemblages these millets could be broken down into two size and shape modalities. The most common type present in the Southern Neolithic is large and more evenly rounded or ovate (modally 1.5×1.3 mm) with a deep scutellum and a rounded apex, with the apex of the scutellum often acute and the hilum relatively shallow and elliptical. These specimens therefore come closest to *Brachiaria ramosa* or *Setaria italica,* although their size, which tends to overlap the larger *S. verticillata* specimens, suggests that they are more likely to be the smaller *B. ramosa*. This identification is further supported by preliminary SEM study of pericarp cell patterns and preserved lemma/palea fragments.

   There are no previous reports of *Brachiaria ramosa* in south Asian archaeobotany, although it may have been misidentified as *Setaria* sp. and possibly even *Eleusine coracana* (see Fuller 1999, 2002, 2003). *B. ramosa* is a relict cultivar today, found in pockets of south India and including some domesticated populations with high pro-portions of non-dehiscent spikelets (de Wet 1995; Grub-ben and Partohardjono 1996; Kimata et al. 2000).

Setaria verticillata (L.) P. Beauv. type

Also amongst the ovate, long-scutellum millets were smaller, thinner ovate caryopses (modally 1×0.8 mm). They often narrow towards their apex, which is sometimes pointed (Fig. 4). These show the strongest resemblance to *Setaria verticillata* or *S. sphaceleata,* with the former being more likely for reasons of general size. This identification is clarified by the presence of adhering fragments of lemma/ palea on some specimens and the occasional presence of hulled caryopses that match the lemma/palea patterns of *S. verticillata.* In addition, preliminary SEM study of pericarp cell patterns suggests that these species may be separated by this means as well.

Setaria has been widely reported in south Asian archaeobotany but may require re-examination. It is usually attributed to *S. italica,* and comparative study of lemma and paleas by Vishnu-Mittre and Savithri (1978) supports that attribution at Surkotada. Identification criteria, however, have not explicitly taken into account *Brachiaria ramosa* which has a rugose lemma like *Setaria* (most similar to *S. verticillata*) and caryopses similar in morphology to those of *S. italica.* Furthermore, reported identifications of *Setaria* sp. have relied entirely on preserved spikelets, with intact lemma and palea, while de-hulled caryopses have often been overlooked, and may in many cases have been mis-attributed to *E. coracana* (Fuller 2002, 2003).

In modern times, *Setaria verticillata* is known to be gathered as human food from wild stands in parts of south India (Gammie 1911), and Maheshwari and Singh (1965) indicate that it is sometimes cultivated.

Other native millet grasses

Three other native millet-grasses were identified in the present material (Fig. 4). Given the limited number of finds of these species, it is unlikely that they were major components of the diet and may have been present as the weeds of the two predominant millet-grasses. At HRP, amongst the long-scutellum millets already described were a few specimens that could be attributed to *Echinochloa* cf. *colona.* These have a truncate basal end with the maximum breadth usually displaced in this direction. They sometimes have a convex scutellum and generally have a noticeably deep, round or widely ovate hilum. These cannot be clearly differentiated from *E. crus-galli,* although *E. colona* is more widely reported in the south Indian flora and has been cultivated in the region in recent times (de Wet et al. 1983a; Singh 1988).

Panicum sumatrense Roth. ex. Roemer et Schultes (syn. *P. miliare* auct. pl.) seeds are similar in size and shape to small *Setaria* spp. and smaller specimens of *Brachiaria ramosa* and *Echinochloa colona. P. sumatrense,* however, is distinctive for its shorter and shallower scutellum and consistently has a pointed apex, which is rare in the other millet genera mentioned. In overall shape it varies from elongate-ovate to nearly round. Most archaeological specimens are probably too small to be *P. miliaceum* even allowing for shrinkage due to charring. *P. sumatrense* was identified in small quantities only at HLR, and therefore may not have been an important food item. Today *P. sumatrense* is a widespread minor crop in India (de Wet et al. 1983b)

Paspalum scrobiculatum was found from the lowest stratum at Kurugodu and additional examples came from the upper Neolithic samples at Hallur. These seeds have an extremely short and shallow scutellum, less than one-third the overall caryopsis length. They have rather flattened ventral surfaces with a more dome-like dorsal surface. The hilum in *Paspalum* spp. is distinctive in being long and linear. *P. scrobiculatum* has previously been reported from a number of archaeological sites dating to the 2nd millennium B.C. throughout India (Kajale 1977a; Vishnu-Mittre et al. 1984; Vishnu-Mittre et al. 1986; Weber 1991; Saraswat et al. 1994). Evidence for cultivation in south India is suggested by the large quantities from first millennium B.C. Veerapuram in Kurnool district (Kajale 1984).

Eleusine coracana (L.) Gaertn.

Eleusine coracana (finger millet) is a widespread cultivar in south Asia, and was domesticated from wild populations in the East African highlands (Hilu and de Wet 1976; Hilu and Johnson 1992). The numerous widespread reports of *E. coracana* in India during the later 3rd and 2nd millennia B.C., including from the Southern Neolithic (Vishnu-Mittre 1971; Devaraj et al. 1995), need to be regarded with scepticism due to the lack of clear identification criteria (Fuller 1999, 2002, 2003; cf. Hilu et al.1979). Indeed, a number of reports illustrated with photographs appear to be misidentified caryopses of *Setaria* sp., *Brachiaria ramosa* or *Echinochloa* sp. (Fuller 1999, 2002, 2003)

In the current study, a single specimen of *E. coracana* was recovered in the large assemblage from HLR.98B (probably from Neolithic Phase III, perhaps late in this phase). Although initially complete, the fragile specimen was broken in handling and the larger intact piece was drawn (Fig. 5). This specimen is subglobose and slightly squarish, measuring 1.2 mm L, approx. 1 mm wide, 0.9 mm thick. It has a large well-preserved scutellum that projects at the base. The hilum was not intact. The base is longitudinally furrowed, a trait that is occasional in populations of *E. coracana* grains. In section the embryo is short and relatively 'shallow' like that in *E. coracana.* While the pericarp was not preserved over the embryo area, it was present elsewhere and noticeably better preserved than much of the internal cotyledon. The pericarp surface was cracked and preserved to varying thickness, indicating that the surface was not well preserved. Nevertheless under magnifications of 40x and above with oblique light a few pusticulae (small round projections from the surface like pimples) could be detected, which were further examined on one fragment under the SEM.
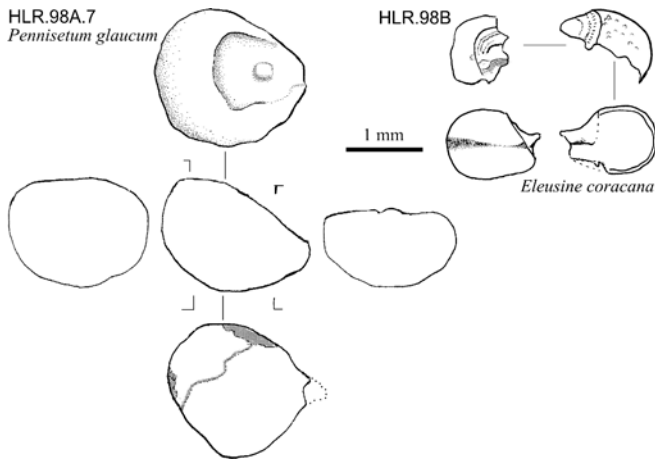
Fig. 5 Drawings of identifiable archaeological specimens of African millets, *Pennisetum glaucum* (pearl millet) and *Eleusine coracana* (finger millet), from Hallur

Thus despite poor preservation of the pericarp, traces of the characteristic surface texture of *E. coracana* support identification.

Pennisetum glaucum (L.) R. Br.

Pennisetum glaucum (syn. *P. americanum* (L.) Leeke, pearl millet) is another cereal crop of widespread importance in traditional Indian agriculture that derives from domestication in Africa (Brunken et al. 1977). Recently isozymic classification suggests that domesticated *P. glaucum* derives from wild populations from the far western African savanna and/or the Lake Chad region (Tostain 1992, 1998). Archaeological finds in south Asia have been few, although small quantities have been reported from Babor Kot (Reddy 1994) and Rangpur (Ghosh and Lal 1963) in Late Harappan Gujarat (2,000-1,700 cal B.C.). Larger quantities were recovered from Kaothe, a Chalcolithic site in Maharashtra (from 2,400–2,200 cal B.C. based on a single radiocarbon date), although there were some concerns at that site over the possibility of contamination by more recent burnt seeds (Kajale 1990). It was also found at Narhan, after ca. 1,200 cal B.C. (Saraswat et al. 1994).

In the present study, material that can be identified to *P. glaucum* was found at Hallur, although in very small quantities. A single well-preserved caryopsis from HLR.98A.7 is widely ovate as is typical of single-seeded spikelets of *P. glaucum*. Other specimens comparable to *P. glaucum* are incompletely preserved with the basal scutellum portion completely burned away. The find from Hallur therefore adds to the small body of evidence for the presence of *Pennisetum* in India by the first half of the 2nd millennium B.C. This is comparable to, or earlier than, the currently available evidence in Africa (D'Andrea et al. 2001).

Hordeum vulgare L.

Hordeum vulgare L. (barley) was found in small quantities from five sites in this study, with its highest ubiquity at SGK where it occurred in 75% of the samples. Amongst the corpus of barley from the latter site there was some evidence for four/six-row barley from asymmetrical and twisted grains. Both hulled and naked barley grains were present. Barley is very widespread on south Asian archaeological sites of the 3rd and 2nd millennia B.C. (Kajale 1991; Saraswat 1992; Fuller 2002), including sites in the Ganges Basin, Chalcolithic Maharashtra and the greater Indus valley. Barley was already cultivated by the 6th millennium B.C. in Baluchistan, Pakistan and was one of the staples of the Harappan civilisation (Costantini and Biasini 1985; Fuller and Madella 2001).

Triticum spp.

Wheat was found widely amongst the sites under study, although usually in low frequencies. In cases where preservation allowed identification, *T. diococcum* type grains and *T. durum/aestivum* (free-threshing) grains co-occurred. No remains of wheat chaff were recovered. On the analogy of modern wheat geography in India we would expect the Neolithic *T. aestivum/durum* to be *T. durum*, as *T. durum* is the most widespread wheat in the agriculture of peninsular India (Pal 1966). *T. diococcum* and a free-threshing wheat (reported as hexaploid *T. sphaerococcum* and/or *T. aestivum*) were present by the 6th millennium B.C. in Baluchistan, Pakistan and the alleged *T. sphaerococcum* has long been considered a staple of the Harappan civilisation (Vishnu-Mittre and Savithri 1982; Costantini and Biasini 1985; cf. Fuller and Madella 2001). Specific identification of free-threshing wheats in south Asia must be regarded with scepticism as almost no reports are accompanied by examination of the characteristic chaff (Fuller 2002; for an exception see Tengberg 1999).

Oryza sp.

Oryza sativa (rice) is an important crop in south Asia, although in the region covered by the current study it is traditionally less important (Watt 1908). The wild progenitors of the Asian cultivated rices *O rufipogon* and *O. nivara* are most widely distributed in northern and eastern India through mainland southeast Asia and southern China (Vaughan 1994; Chang 1995), although spontaneous rice populations are also reported from northwestern Karnataka (Akihama and Toshimitsu 1972). The limited and isolated distribution of these south Indian wild rices suggests that they may be relict populations of true wild rice, rather than feral populations. Another local wild candidate for this material is the forest floor species *O. granulata* which is distributed in the western Ghats (Fischer 1928; Vaughan 1994). The available evidence

indicates the dispersal of rice cultivation from the central Ganges valley by the mid- 3rd millennium B.C.. (Fuller 2002). The published record indicates a negligible presence of rice on the Indian peninsula during the 2nd millennium B.C., but widespread cultivation during the 1st millennium B.C. in at least some areas (Kajale 1989a; Fuller 2002).

Among the assemblages considered here, small quantities of *Oryza* sp. grains were found throughout the sequence at Hallur, including whole and fragmentary caryopses and silicified lemma/ palea fragments. *Oryza* sp. probably cannot be distinguished reliably to species level on the basis of charred caryopses (cf. Thompson 1996), although the rice genus itself is unmistakeable, with its grooved caryopses and indented embryo. Lemmas and paleas have a distinctive 'chequered' appearance, with longitudinal and transverse intersecting ribs. The limited quantity of these finds and their isolation on one site suggests that they may derive from wild sources.

Cucurbitaceae, *Cucumis* cf. *prophetarum* L. and cf. *Luffa cylindrica* (L.) Roem.

The seeds of this family are usually readily recognisable by their ovate shape and flattened section with an acute tip (base), or if rounded a winged tip (as in *Citrullus, Luffa*). Some 15 genera are reported as components of the native Karnataka flora, in addition to three introduced as domesticates (Saldanha 1984), although only six genera were available in the reference collection. Two types have been encountered in the present material, both of which fit with known food genera. Ovate seeds and an acute tip and a testa cell pattern consisting of regular longitidinally linear rows of rectangular cells can be referred to *Cucumis,* from HLR and HRP (Fig. 6). They appear similar to *C. prophetarum*, the only species native to south India, a species noted to be edible by Sturtevant (1972 [1919]).

Another cucurbit present in the material may also be a cultivar. Fragments of a large cucurbit seed with an irregular (rough) surface and a rounded tip with square wings are a good match for *Luffa cylindrica* (L.) Roem., one of the species from which commercial fibre luffas (loofahs) derive, but which is also edible when the fruits are still young. This taxon has been found at HLR.

Gossypium cf. *arboreum* L.

Cotton seed fragments were recovered from the latest HLR sample (Fig. 7). Although no complete seeds were found, the fragments all of which came from the testa, clearly came from a large ovate seed. The seed coat is thick and layers show the hexagonal cell pattern on the inner preserved surface that is typical of the inner layer of the testa (cf. Vaughan 1970). Most importantly, most of these fragments include adhering cotton lint. The current specimens are considered most likely to be *G. arboreum* which could be native to the region (Hutchinson and Ghose 1937) rather than *G. herbaceum* L., which is thought to have been introduced to India in the last few centuries (Santhanam and Hutchinson 1974).

Linum cf. *usitatissimum* L. (Linaceae)

Linum has been identified from latest HLR on the basis of a few seed fragments, including one of the characteristic seed apex, with a hooked tip and lateral hilum. The surface is variously sculptured reflecting the differential preservation of different cell layers of the testa, including finely reticulate cells, which probably corresponds to one of the innermost layers of the testa, the 'pigment cells', while otherwise ruminate cells reflect uneven preservation of the testa layers (cf. Vaughan 1970, pp 141–143). Although cultivated linseed (*L. usitatissimum*) is plausible, the indigenous *L. mysurense* Heyne ex Benth. (Saldanha 1996) cannot be ruled out.

Ziziphus cf. *mauritania* Lam.

The thick-walled woody, rugose stones of *Ziziphus* spp. are readily recognisable, and fragments can often be identified by the rugose surface pattern or by preservation of the semi-circular internal cavities that divide the stone in half. Although all of the archaeological specimens match modern reference material of *Z. mauritania* collected by the first author in Karnataka, there are seven other *Ziziphus* species in the native flora (Saldanha 1996) which cannot be ruled out.

Discussion

The archaeobotanical evidence from this study provides direct evidence of the probable plant food staples of the Southern Neolithic, as well as a number of supplementary species. The widespread crop package, cross-cutting archaeological subdivisions within the Southern Neolithic as well as modern vegetational zones, included two pulses, *Macrotyloma uniflorum* and *Vigna radiata,* and two millet grasses, identified as *Brachiaria ramosa* and *Setaria verticillata. Vigna radiata* can be inferred to have been domesticated, due to its presence beyond its probable wild range. Available evidence indicates no major climatically-driven shifts in vegetational zones since the late 3rd millennium B.C. (Fuller 1999; Caratini et al. 1994; Meher-Homji 1996; cf. Fuller and Madella 2001). Given that *V. radiata,* and non-native species, such as *Hordeum* and *Triticum,* must have been cultivated, it is plausible that the other native staples were also cultivated. Thus the evidence indicates that Southern Neolithic cultivation was based largely on native species that could have been brought into cultivation in this region. This may have occurred in the transitional zone of wet to dry deciduous forest, especially the hilly ecozones on the eastern side of

Fig. 6A–K Scanning electron micrographs of selected millets, *Gossypium* and *Cucumis*. **A**: *Brachiaria ramosa* from HRP.1–5, note maximum width near centre. **B**: Close-up of pericarp surface of A, note shallow, wide undulations. **C**: *Setaria verticillata* from HLR.98A.3, note difference in scale from A. **D**: *Setaria verticillata* spikelet base fromTKT.98B.2E, note smooth abscission scar. **E**: *Echinochloa* cf. *colona* from HLR.98B, note blunt base (*to left*). **F**: Close-up of pericarp surface of E, note deep, constricted undulations. **G**: *Gossypium* sp. seed fragment with adhering cotton lint from HLR.98B. **H**: Close-up of lint in G. **I**: *Cucumis* cf. *proferatum,* from HLR.98B. **K**: Close-up of testa of I
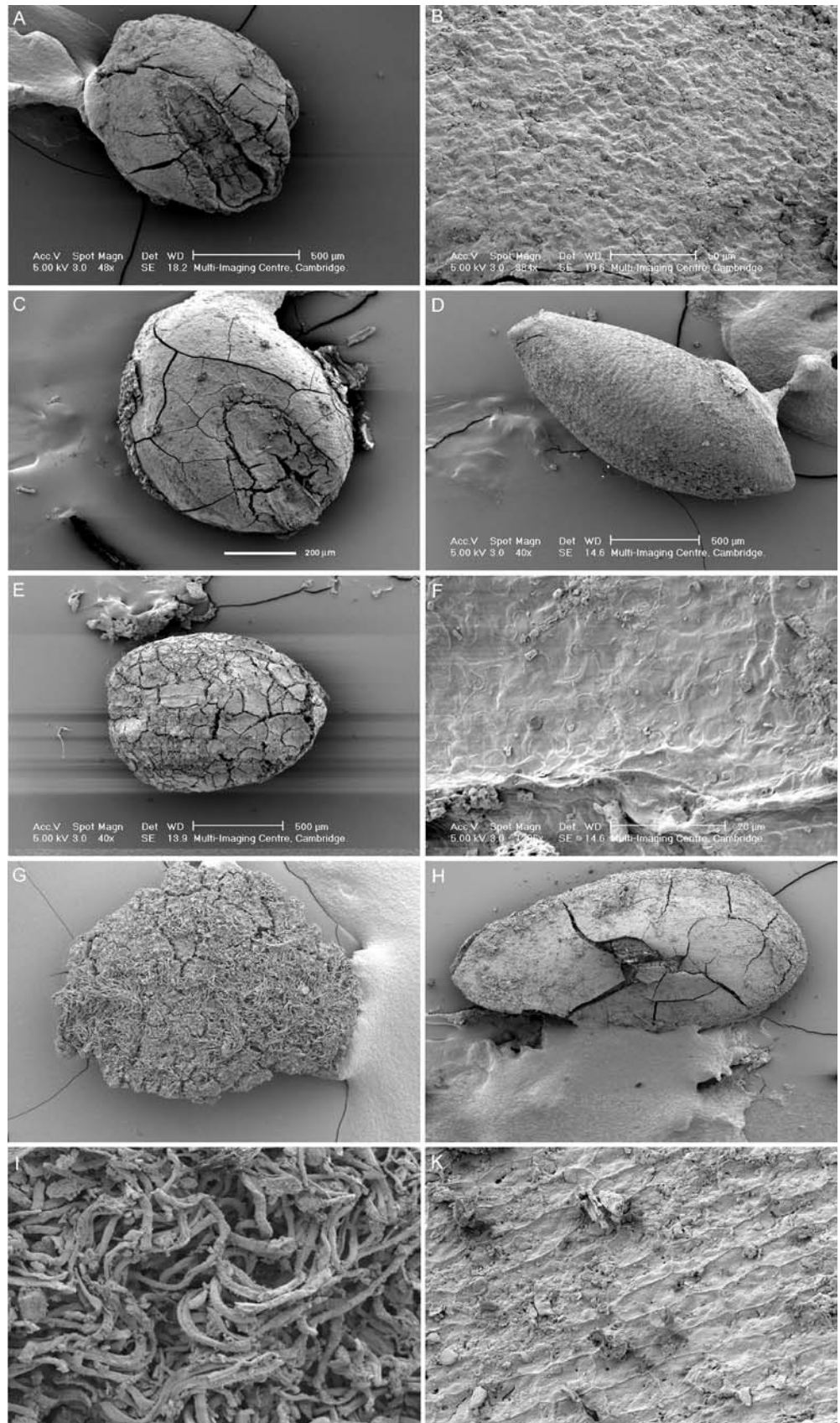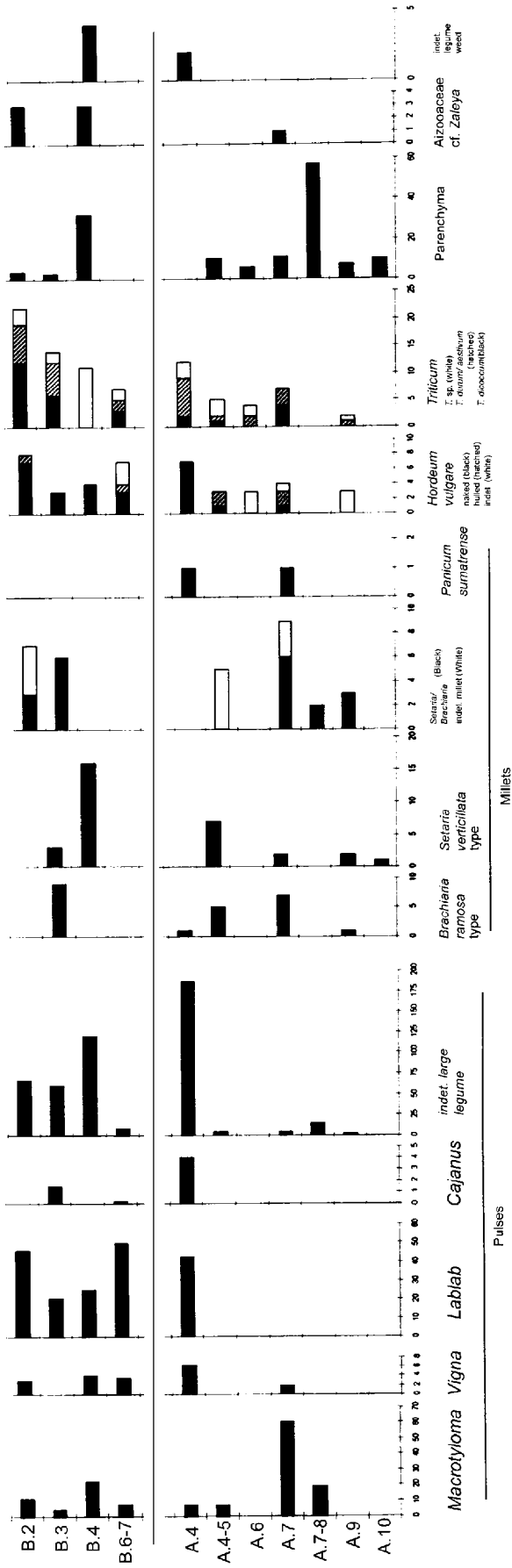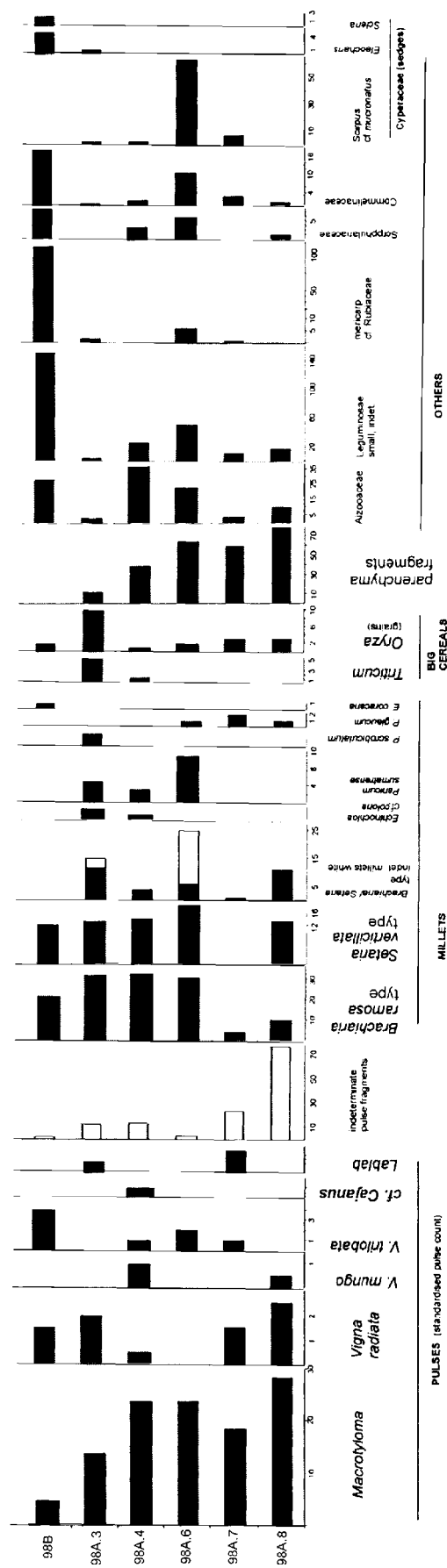
Fig. 7 Multi-histogram of changing quantities of crops parenchyma and the most common weed types through the sequence at Sanganakallu, expressed as absolute counts. The bottom half of the chart derives from a single sample for each stratum from profile SGK.98A, while the top half derives from trial trench SGK.98B strata. Preliminary field assessment of ceramics and depth suggest that SGK.98A.4 is possibly equivalent to SGK.98B.4; while A.4–5 is equivalent to B.6–7. SGK.98A can be correlated with previous excavations and dating evidence (Subbarao 1948; Ansari and Nagaraja Rao 1969). SGK.98A.6–10 represent Phase II (of Allchin and Allchin 1982), SGK.98A.4–5/B.6–7 and above represents Phase III

Fig. 8 Multi-histogram of changing quantities of crops, parenchyma and the most common weed types through the sequence at Hallur. Quantities represent absolute identifiable fragment counts and are thus scaled separately for each taxon. For pulses, cotyledons have been counted as 1/2 and identifiable fragments of cotyledons as 1/4. Ceramic data indicates that this sequence incorporates material from phases II-III of the Southern Neolithic

the Western Ghats where all four species would have occurred wild.

The presence of charred parenchyma fragments suggests the likelihood of tuber/rhizome use. Preliminary evidence indicates much larger quantities of parenchyma tissue in earlier levels than are present in samples of later periods (Figs. 7 and 8). This appears to be the reverse of the case with cereals, especially millets, which increase in frequency in upper levels. This could indicate that millets became increasingly important through time, perhaps as field cultivation replaced tuber use. Harris (1972, 1973) has drawn attention to the potential importance of tuber food sources in the semi-arid tropics and the possibility that they may have preceded grain-based agriculture. The plausibility of tuber use highlights the need for future anatomical study of charred parenchyma from sites in southern India.

The small quantity of wheat and barley, as well as flax from Hallur, indicates that other crops were adopted from regions to the north. That the species are absent from many sites suggests that they were not the primary subsistence of the Southern Neolithic.

The presence of winter-cultivated crops (wheat and barley) in the dry, monsoonal Deccan implies some form of irrigation agriculture near some Neolithic sites, as inferred by Kajale for Inamgaon in Maharashtra (Kajale 1988). This may call into question the traditional assumption of historians that tank irrigation emerged in south India only in the period of the 1st millennium B.C. or later (Wheeler 1959:163; Gurukkal 1989; Champakalakshmi 1996:36, 82–83). This adoption of wheats and barley, in a region to which they are not ecologically suited, and where barley has not been grown on any significant scale in the recent past (Watt 1908), may be attributable to the social values attached to these cereals (cf. Hayden 1995).

Conclusions

The evidence presented above suggests that native species were domesticated before the arrival of introduced species. It is therefore possible that south India represents a region of independent agricultural origins, albeit rather late by comparison to other world regions. While the evidence of this study does not come from the earliest phase of the Southern Neolithic (dated to the beginning of the 3rd millennium B.C.), nor from the transition from hunting-and-gathering to herding-and-cultivating, the evidence is suggestive. This archaeobotanical picture must be considered alongside the faunal evidence for the introduction of sheep and goats and perhaps cattle, although cattle could have been domesticated from wild populations in the region (Allchin and Allchin 1974; 1982; Alur 1990; Thomas and Joglekar 1994). Nevertheless, more research is needed to assess the possibility of northern influences or even immigrants promoting the emergence of peninsular agriculture, as many hypotheses suggest (e.g. Allchin 1963; Paddayya 1973; Murty 1989). Most

general syntheses of agricultural origins view Indian agriculture as largely derivative and secondary (for example, Hawkes 1983; Harlan 1992; MacNeish 1992), but the current evidence might be seen as support, at least in part, for Vavilov's Indian Centre of Origin (Vavilov 1992). Clearly the current study highlights the potential for problem-oriented research into the beginnings of agriculture in south India.

References

Akihama T, Toshimitsu K (1972) Geographical distribution of morphological variation on wild rices in Central and Southern India. In: Watabe T (ed) Origin and alteration of cultivated rice in the Indian Sub-continent, Volume 1. Tottori University, Japan, pp 48–59

Allchin FR (1963) Neolithic cattle keepers of south India: a study of Deccan ashmounds. Cambridge University Press, Cambridge

Allchin B, Allchin FR (1974) Some new thoughts on Indian cattle. In: Louizen-Deleeuw JE van, Ubaghs JMM (eds) South Asian Archaeology 1973. EJ Brill, Leiden, pp 71–77

Allchin B, Allchin FR (1982) The rise of civilization in India and Pakistan. Cambridge University Press, Cambridge

Allchin B, Allchin FR (1997) Origins of a civilisation. The prehistory and early archaeology of south Asia. Penguin Books India, New Delhi

Alur KR (1990) Studies in Indian archaeology and palaeontology. Shrihari Prakashana, Dharwad

Ansari ZD, Nagaraja Rao (1969) Excavations at Sangankallu. Deccan College, Poona

Brunken J, Wet JMJ de, Harlan JR (1977) The morphology of domestication and pearl millet, Economic Botany 31:163–174

Caratini C, Bentaleb I, Fontugne M, Morzadec-Kerfourn MP, Pascal JP, Tissot C (1994) A less humid climate since ca. 3500 yr B.P. from marine cores off Karwar, western India. Palaeogeography, Palaeoclimatology, Palaeoecology 109:371–384

Champakalakshmi R (1996) Trade, ideology and urbanization. South India 300 B.C. to A.D. 1300. Oxford University Press, Delhi

Chandel KPS, Lester RN, Starlin RJ (1984) The wild ancestors of urid and mung beans (*Vigna mungo* (L.) Hepper and *V. radiata* (L.) Wilczek). Botanical J Linnean Society 89:85–96

Chang TT (1995) Rice (Oryza). In: Smartt J, Simmonds NW (eds) Evolution of crop plants, second edition. Longman, Harlow, pp 147–155

Costantini L, Biasini LC (1985). Agriculture in Baluchistan between the 7th and 3rd Millennium B.C.. Newsletter of Baluchistan Studies 2:16–37

D'Andrea AC, Klee M, Casey J (2001). Archaeobotanical evidence for pearl millet (*Pennisetum glaucum*) in sub-Saharan West Africa. Antiquity 75:341–348

De DN (1974) Pigeon pea. In: Hutchinson J (ed) Diversity and change in the Indian subcontinent. Cambridge University Press, Cambridge, pp 79–88

Devaraj DV, Shaffer JG, Patil CS, Balasubramanya (1995) The Watgal excavations: an interim report. Man and Environment 20:57–74

Dhavalikar MK (1994) Early farming communities of central India. Man and Environment 19:159–168

Fischer CEC (1928) Flora of the Presidency of Madras, Volume III. Adlard, London

Fuller DQ (1999) The emergence of agricultural societies in South India: Botanical and archaeological perspectives, unpublished PhD dissertation, Cambridge University

Fuller DQ (2002) Fifty years of archaeobotanical studies in India: laying a solid foundation. In: Settar S, Korisettar R (eds) Indian archaeology in retrospect, Volume III. Archaeology and interactive disciplines. Manohar, New Delhi, pp 247–363

Fuller DQ (2003) African crops in prehistoric South Asia: a critical review. In Neumann K, Butler A, Kahlheber S (eds) Food, fuel and fields. Progress in African archaeobotany. Heinrich-Barth Institut, Köln, pp 239–71

Fuller DQ, Madella M (2001). Issues in Harappan archaeobotany: Retrospect and prospect. In: Settar S, Korisettar R (eds) Indian Archaeology in Retrospect, Vol. II. Protohistory. Manohar, New Delhi, pp 317–390

Fuller DQ, Venkatasubbaiah PC, Korisettar R (2001) The beginnings of agriculture in the Kunderu River basin: Evidence from archaeological survey and archaeobotany. Puratattva 31:1–8

Gamble JS (1935) Flora of the Presidency of Madras, Volume I. Adlard and Son, London

Gammie GA (1911). Millets of the genus *Setaria* in the Bombay Presidency and Sind. Memoirs of the Department of Agriculture in India, Botanical Series 4, pp 1–8

Ghosh SS, Lal K (1963) Plant remains from Rangpur and other explorations in Gujarat. Ancient India 18–19:161–175

Grubben GJH, Partohardjono S (1996) Plant Resources of South-East Asia, No. 10. Cereals. PROSEA, Bogor, Indonesia

Gurukkal R (1989). Forms of production and forces of change in ancient Tamil society. Studies in History 5:159–175

Harlan JR (1992) Crops and man, second edition. Society for American Agronomy, Madison

Harris DR (1972) The origins of agriculture in the tropics. American Scientist 60:180–193

Harris DR (1973) The prehistory of tropical agriculture: an ethnoecological model. In: Renfrew C (ed) The explanation of culture change: models in prehistory. Duckworth, London, pp 391–417

Hawkes JG (1983) The diversity of crop plants. Harvard University Press, Cambridge, Mass

Hayden B (1995) A new overview of domestication. In: Price TD, Gebauer AB (eds) Last hunters, first farmers. New perspectives on the prehistoric transition to agriculture. School of Advanced Research Press, Santa Fe, New Mexico, pp 273–299

Helbaek H (1969) Plant-collecting, dry-farming and irrigation agriculture in prehistoric Deh Luran. In: Hole F, Flannery KV, Neely JA (eds) Prehistory and human ecology of the Deh Luran plain. An early village sequence from Khuzistan, Iran. Memoirs

of the Museum of Anthropology, University of Michigan, 1, pp 383–426

Hilu KW, Wet JMJ de (1976). Racial evolution in *Eleusine coracana* ssp. *coracana* (finger millet). Am J Botany 63:1311–1318

Hilu KW, Johnson JL (1992) Ribosomal DNA variation in finger millet and wild species of *Eleusine* (Poaceae). Theoretical and Applied Genetics 83:895–902

Hilu KW, Wet JMJ de, Harlan JR (1979) Archaeobotanical studies of *Eleusine coracana* ssp. *coracana* (Finger Millet). Am J Botany 66:330–333

Hooker JD (1872–1897) Flora of British India, vol. II. Reeve and Co, London

Hutchinson JB (1976) India: local and introduced crops. Philosophical Transactions of the Royal Society, London, B 275, pp 129–141

Hutchinson JB, Ghose RLM (1937) The classification of the cottons of Asia and Africa. Indian J Agricultural Science 7:233–257

Ignacimuthu S, Babu CR (1985) Significance of seed coat pattern in *Vigna radiata* var. *sublobata*. Proc Indian Academy of Sciences (Plant Science) 94:561–566

Jansen PCM (1989) *Macrotyloma uniflorum* (Lam.) Verdc. In: Maeson LJG van der, Somaatmadji S (eds) Plant resources of south-east asia 1. Pulses. Pudoc, Wageningen, pp 53–54

Kajale MD (1975) A note on grain remains from excavations at Ter (District Osmanbad) in 1975. Bulletin of the Deccan College Research Institute 35:62–65

Kajale MD (1977a) On the botanical findings from excavations at Daimabad, a Chalcholithic site in western Maharashtra, India. Current Science 46:818–819

Kajale MD (1977b) Ancient plant economy at Nevasa during Satavahana and Indo-Roman Period. Bulletin of the Deccan College Research Institute 36:48–61

Kajale MD (1979) On the occurrence of ancient agricultural patterns during the Chalcolithic periods (c. 1600–1000 B.C.) at Apegaon, District Aurangabad in central Godavari valley, Maharashtra. In: Deo SB, Dhavalikar MK, Ansari ZD (eds) Apegaon Excavations. Deccan College Postgraduate and Research Institute, Pune, pp 50–56

Kajale MD (1984) New light on agricultural plant economy during 1st millennium B.C.: palaeobotanical study of plant remains from excavations at Veerapuram, District Kurnool, Andhra Pradesh, Appendix B. In: Sastri TVG, Kasturibai M, Prasada Rao JV (eds) Veerapuram: a type site for cultural study in the Krishna valley. Birla Archaeological and Cultural Research Institute, Hyderabad, pp 15

Kajale MD (1988) Plant Economy. In: Dhavalikar MK, Sankalia HD, Ansari ZD (eds) Excavations at Inamgaon, Vol. 1, Part 2. Deccan College Postgraduate and Research Institute, Pune, pp 727–821

Kajale MD (1989a) Archaeobotanical investigations at Megalithic Bragimohari and its significance for ancient Indian agricultural system. Man and Environment 13:87–100

Kajale MD (1989b) Palaeobotanical findings from excavations at Hallur (second season), district Dharwar, Karnataka. Bulletin of the Deccan College Research Institute, 47–48, pp 109–115

Kajale MD (1990) Observations on the plant remains from excavation at Chalcolithic Kaothe, District Dhule, Maharashtra with cautionary remarks on their interpretations. In: Dhavalikar MK, Shinde VS, Atre SM (eds) Excavations at Kaothe. Deccan College Postgraduate and Research Institute, Pune, pp 265–280

Kajale MD (1991) Current status of Indian palaeoethnobotany: introduced and indigenous food plants with a discussion of the historical and evolutionary development of Indian agriculture and agricultural systems in general. In: Renfew J (ed) New light on early farming—recent developments in palaeoethnobotany. Edinburgh University Press, Edinburgh, pp 155–189

Keeley LH (1992). The use of plant foods among hunter-gatherers: a cross-cultural survey. In: Anderson PC (ed) Préhistoire l'agriculture: Nouvelle approches expérimentales et ethnographiques, Monographie du CRA 6, Editions du CNRS, Paris, pp 29–38

128

Keeley LH (1995) Protoagricultural practices among hunter-gatherers: a cross-cultural survey. In: Price TD, Gebauer AB (eds) Last hunters, first farmers. New perspectives on the prehistoric transition to agriculture. School of American Research Press, Santa Fe, New Mexico, pp 243–272

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

Korisettar R, Venkatasubbaiah PC, Fuller DQ (2001a) Brahmagiri and Beyond: the archaeology of the Southern Neolithic. In: Settar S, Korisettrar R (eds) Indian archaeology in retrospect, volume I. Prehistory Publications of the Indian Council for Historical Research, Manohar, New Delhi, pp 151–356

Korisettar R, Venkatasubbaiah PC, Fuller DQ (2001b) Archaeological re-investigation and archaeozoology of seven Southern Neolithic sites in Karnataka and Andhra Pradesh. Man and Environment 26:47–66

Kroll H (1996) Literature on archaeological remains of cultivated plants (1994/95). Vegetation History and Archaeobotany 5:169–200

Kroll H (1997) Literature on archaeological remains of cultivated plants (1995/96). Vegetation History and Archaeobotany 6:25–67

Kroll H (1998) Literature on archaeological remains of cultivated plants (1996/1997). Vegetation History and Archaeobotany 7:23–56

Lawn R (1995) The Asiatic Vigna species. In: Smartt J, Simmonds NW (eds) Evolution of crop plants (2nd edn), Longman, London, pp 321–326

Linnaeus C (1753) Species plantarum (1st edition). Laurentii Salvii, Helmiae

Lukoki L, Marechal R, Otoul E (1980) Les ancestres sauvages des haricots cultivees: *Vigna radiata* (L.) Wilczek et *V. mungo* (L.) Hepper. Bulletin du Jardin Botanique de Belgique 50:385–391

Maheshwari P, Singh U (1965) Dictionary of economic plants in India. Indian Council for Agricultural Research, New Delhi

MacNeish RS (1992) The origins of agriculture and settled life. University of Oklahoma Press, Norman

Maeson LJG van der (1986). *Cajanus* DC. and *Atylosia* W & A. (Leguminosae). Agricultural University Wageningen Papers 84–85, Agricultural University, Wageningen

Maeson LJG van der (1995) Pigeon pea *Cajanus cajan*. In: Smartt JS, Simmonds N (eds) Evolution of crop plants, 2nd edn. Longman Scientific and Technical, Harlow, pp 251–255

Maréchal R, Mascherpa J-M, Stainier F (1978) Etude taxonomique d'un groupe complexe d'espèces des genres *Phaseolus* et *Vigna* (Papilionaceae) sur la base de données morphologiques et polliniques, traitées par l'analyse informatique. Boissiera 28: 10–273

Meadow R (1996) The origins and spread of agriculture and pastoralism in northwestern South Asia. In: Harris DR (ed) The origins and spread of agriculture and pastoralism in Eurasia. UCL Press, London, pp 390–412

Meadow R (1998) Pre- and proto-historic agricultural and pastoral transformations in northwestern south Asia. The Review of Archaeology 19:12–21

Meher-Homji VM (1967) On delimiting arid and semi-arid climates in India. The Indian Geographical J 42:1–6

Meher-Homji VM (1996) Past environments through palynology: a short appraisal with reference to the Western Ghats. Environment and History 2:249–252

Mehra KL (1997) Biodiversity and subsistence changes in India: the Neolithic and Chalcolithic age. Asian Agri-history 1:105–126

Mehra KL (1999) Subsistence changes in India and Pakistan: the Neolithic and Chalcolithic from the point of view of plant use today. In: Gosden C, Hather J (eds) The prehistory of food. Appetites for change. Routledge, London, pp 139–146

Miyazaki S (1982) Classification and phylogenetic relationships of the *Vigna radiata-mungo-sublobata* complex [Japanese with English summary]. Bulletin of the National Institute of Agricultural Science (Japan), D. 33, pp 1–61

Murty MLK (1989) Pre-Iron Age agricultural settlements in south India: an ecological perspective. Man and Environment 14:65–81

Paddayya K (1973) Investigations into the Neolithic Culture of the Shorapur Doab, south India. EJ Brill, Leiden

Paddayya K (1992) The ashmounds of south India: fresh evidence and possible implications. Bulletin of the Deccan College Post-Graduate and Research Institute, 51–52, pp 573–625

Pal BP (1966) Wheat. Indian Council for Agricultural Research, New Delhi

Possehl GL, Rissman P (1992) The chronology of prehistoric India from earliest times to the Iron Age. In: Ehrich RW (ed) Chronologies in Old World archaeology: vol. 1, pp 465–490, vol. 2, pp 447–474

Puri GS, Meher-Homji RK, Gupta S (1983) Forest ecology (second edition), Vol I. Phytogeography and forest conservation. Oxford and IBH, New Delhi

Ramam PK, Murty VN (1997) Geology of Andhra Pradesh. Geological Society of India, Bangalore

Reddy S (1994) Plant usage and subsistence modeling: an ethnoarchaeological approach to the Late Harappan of Northwest India. PhD Dissertation, University of Wisconsin. Ann Arbor Michigan: University Microfilms

Roxburgh W (1832) Flora Indica, 3 vols. W. Thackery and Co, Calcutta

Saldanha CJ (1984) Flora of Karnataka, Vol I. Oxford and IBH, New Delhi

Saldanha CJ (1996) Flora of Karnataka, Vol II. Oxford and IBH, New Delhi

Sanathnam V, Hutchinson JB (1974) Cotton. In: Hutchinson JB (ed) Evolutionary studies in world crops. Diversity and change in the Indian subcontinent. Cambridge University Press, Cambridge, pp 89–100

Saraswat KS (1992) Plant economy of Late Harappan at Hulas. Puratattva 23:1–12

Saraswat KS, Sharma NK, Saini DC (1994) Plant economy in ancient Narhan (ca. 1,300 B.C. - 300/400 A.D.). In: Purushottam Singh P (ed) Excavations at Narhan (1984–1989). Banaras Hindu University, Varanasi, pp 255–346

Sharma K, Babu CR, Johri BM, Hepworth A (1977) SEM studies on seed coat patterns in *Phaseolus mungo-radiatus-sublobatus* complex. Phytomorphology 27:106–111

Shinde VS (1994) The Deccan Chalcolithic: a recent perspective. Man and Environment 19:169–178

Singh NP (1988) Flora of Eastern Karnataka, 2 vols. Mittal Publications, Delhi

Smartt J (1985a) Evolution of grain legumes. II. Old and New World pulses of lesser economic importance. Experimental Agriculture 21:1–18

Smartt J (1985b) Evolution of grain legumes. III. Pulses in the genus *Vigna*. Experimental Agriculture 21:87–100

Smartt J (1990) Grain legumes: evolution and genetic resources. Cambridge University Press, Cambridge

Sturtevant EL (1972 [1919]) Edible plants of the world. Dover, New York

Subbarao B (1948) The Stone Age cultures of Bellary. Deccan College, Poona

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

Thomas PK, Joglekar P (1994) Holocene Faunal Studies. Man and Environment 19:179–203

Thompson GB (1996) The Excavation of Khok Phanom Di a prehistoric site in Central Thailand. Vol IV: subsistence and environment: the botanical evidence (the biological remains, Part II). The Society of Antiquaries of London

Tostain S (1992) Enzyme diversity in pearl millet (*Pennisetum glaucum* L.) 3. Wild millet. Theoretical and Applied Genetics 83:733–742

Tostain S (1998) Le mil, une longue histoire: hypotheses sur sa domestication et ses migrations. In: Chastenet M (ed) Plantes et paysages d'Afrique. Une histoire a explorer. Editions Karthala and Centre de Recherches Africaines, Paris, pp 461–490

Vaughan DA (1994) The wild relatives of rice. A genetic resources handbook. International Rice Research Institute, Manila

Vaughan JG (1970) The structure and utilization of oilseeds. Chapman and Hill, London

Vavilov NI (1992) The origin and geography of cultivated plants. Cambridge University Press, Cambridge

Verdcourt B (1971) Phaeseoleae. In: Milne-Redhead E, Polhill RM (eds) Flora of Tropical East Africa, Leguminosae (Part 4), Papilionidae (2). Crown Agents for Overseas Governments and Administrations, London

Vishnu-Mittre (1961) Plant economy in ancient Navdatoli-Maheshwar. In: Sankalia HD (ed) Technical report on archaeological remains. Department of Archaeology and Ancient Indian History, Deccan College and University of Poona Publications 2, Pune, pp 13–52

Vishnu-Mittre (1971). Ancient plant economy at Hallur. In: Nagaraja Rao MS (ed) Protohistoric cultures of the Tungabhadra Valley (Hallur excavations). Published by the author, Dharwar, pp 1–9

Vishnu-Mittre (1989) Forty years of archaeobotanical research in South Asia. Man and Environment 14:1–16

Vishnu-Mittre, Savithri R (1978) *Setaria* in ancient plant economy of India. The Palaeobotanist 25:559–564

Vishnu-Mittre, Savithri R (1982) Food economy of the Harappans. In: Possehl GL (ed) Harrapan Civilization. Oxford and IBH, New Delhi, pp 205–221

Vishnu-Mittre, Sharma A, Chanchala (1984) Palaeobotanical and pollen analytical investigations. Indian Archaeology 1981–82, A Review, pp 105–106

Vishnu-Mittre, Sharma A, Chanchala (1986). Ancient plant economy at Daimabad. In: Sali SA (ed) Daimabad 1976–1979. Archaeological Survey of India, New Delhi, pp 588–626

Watt G (1908) The commercial products of India—an abridgement of "The dictionary of the economic products of India". John Murray, London

Weber S (1991) Plants and Harappan subsistence. An example of stability and change from Rojdi. Oxford and IBH, New Delhi

Weber S (1999) Seeds of urbanism: palaeoethnobotany and the Indus Civilization. Antiquity 73:813–26

Westphal E (1974) Pulses in Ethiopia, their taxonomy and agricultural significance. Agricultural Research Reports 815. Centre for Agricultural Publishing and Documentation, Wageningen

Wet JMJ de (1995) Minor cereals. In: Smartt J, Simmonds NW (eds) Evolution of crop plants, second edition. Longman, Harlow, pp 202–207

Wet JMJ de, Prasad Rao KE, Mengesha MH, Brink DE (1983a) Domestication of Sawa millet (*Echinochloa colona*). Economic Botany 37:283–291

Wet JMJ de, Prasada Rao KE. Brink DE (1983b) Systematics and domestication of *Panicum sumatrense* (Graminae). J d'Agriculture Traditionelle et de Botanique Appliquée 30:159–168

Wheeler M (1959) Early India and Pakistan. Thames and Hudson, London

Whyte RO (1964) Grassland and fodder resources of India, revised edn. Indian Council for Agricultural Research scientific monograph 22, New Delhi

Willcox G (1992) Some differences between crops of Near Eastern origin and those from the tropics. In: Jarrige C (ed) South Asian Archaeology 1989, Monographs in World Archaeology 14. Prehistory Press, Madison, pp 291–299

Zeven AC, Wet JMJ de (1982) Dictionary of cultivated plants and their regions of diversity. Centre for Agricultural Publishing and Documentation, Wageningen