

Palaeoethnobotanical record of cultivated crops and associated weeds and wild taxa from Neolithic site, Tokwa, Uttar Pradesh, India

Anil K. Pokharia

Birbal Sahni Institute of Palaeobotany, 53, University Road, Lucknow 226 007, India

Investigation of botanical remains from an ancient site, Tokwa at the confluence of Belan and Adwa rivers, Mirzapur District, Uttar Pradesh (UP), has brought to light the agriculture-based subsistence economy during the Neolithic culture (3rd–2nd millennium BC). They subsisted on cereals, viz. *Oryza sativa*, *Triticum aestivum* and *Hordeum vulgare*, supplemented by leguminous seeds of *Lens culinaris*, *Pisum arvense* and *Vigna radiata*. Evidence of oil-yielding crops has been documented by recovery of seeds of *Linum usitatissimum* and *Brassica juncea*. Fortuitously, an important find among the botanical remains is the seeds of South American custard apple, regarded to have been introduced by the Portuguese in the 16th century. The remains of custard apple as fruit coat and seeds have also been recorded from other sites in the Indian archaeological context, during the Kushana Period (AD 100–300) in Punjab and Early Iron Age (1300–700 BC) in UP. The factual remains of custard apple, along with other stray finds discussed in the text, favour a group of specialists, supporting with diverse arguments, the reasoning of Asian–American contacts, before the discovery of America by Columbus in 1498. Further, a few weeds have turned up as an admixture in the crop remains.

Keywords: Custard apple, neolithic site, palaeoethnobotany, subsistence economy.

INVESTIGATING human–plant relationship during the Dark Ages is one of the central questions in palaeoethnobotany. The aim of this communication is to present the results of the charred plant remains recovered through archaeological excavations from the Neolithic level at an archaeological site, Tokwa, and discuss these in the light of the information on agricultural remains from other sites in the Vindhyan region.

Tokwa (lat. 24°54'20"N; long. 83°21'65"E) is situated at the confluence of the Belan and Adwa rivers in Mirzapur District, Uttar Pradesh (UP), in SE direction from Mirzapur city (Figures 1 and 2a and b). At present, the ancient mound covers an area of about 27,597 sq. m. The northern margin of the site is flanked by the Belan river, while the southern margin faces the Adwa river. The

western margin of the site looks like the peak of the triangle¹. Archaeological excavations at this site had begun in 2000 by Misra and co-workers (University of Allahabad), and continued till 2003. The combined testimony of the excavation of trenches H-8, H-9, I-8, I-9 and control pits brought to light the archaeological evidence of three cultures: Neolithic, Chalcolithic and Iron Age. The occupational strata divisible into as many as 16 layers, measured 4.00 m. The botanical samples studied from the Neolithic culture reveal the finds of cereals, pulses, oil-seeds and weeds and wild taxa.

Three radiocarbon dates of charcoal samples from different layers belonging to the Neolithic level from Tokwa are available. Their calibrated values in BP and BC are given in Table 1.

Table 1 shows that only two dates (BS-2370, BS-2054), appear to be consistent to some extent; however, disturbance in dates is apparent due to mixing of the material. Moreover, the other date (BS-2369) corresponds to early dates from Koldihwa, Jhusi² and Lahuradewa^{3,4}. It is to be mentioned here that there is a sharp slope in the layers at the site, and in the northern and eastern areas of the trenches these are considerably thin. Thus there is the possibility of mixing the materials. The main objective here is to present the botanical findings. However, based on radiocarbon dates of other Neolithic cultural sites in this region, the botanical remains from this site have been discussed within a time range 3rd–2nd millennium BC.

The studied plant material was obtained by water flotation technique during the course of excavations in 2000 and 2003. The soil from varied horizons at different depths in the cultural deposits was poured into a wash-tub filled with water and agitated, so that carbonized light material buoyed to the surface and skimmed-off through a standard geological sieve of 25 mesh.

Scrutiny of the contexts in which seed and fruit assemblages occur is also critical in deducing the sources and human activities that led to their deposition in the strata. Equal chances of exposure to fire do not necessarily lead to equal chances of preservation. Therefore, certain types of remains would have more likely been accidentally carbonized and preserved than others. Some remains have also been recovered from the pits.

By and large the grains, seeds and fruit remains in carbonized state were found to be better preserved from the deposits with little or no ash. In some cases, severe carbonization made the grains and seeds devoid of diagnostic features. The recovered botanical remains are discussed below:

Oryza sativa L. (rice, Figure 3b and e): Sixty-nine more or less complete and some broken grains could be segregated from the mixture. Practically all the grains were without husk. Grains were elongate to narrowly oblong, flattened and ribbed. Ribs varied from 3 to 4 in number.

e-mail: apokharia@yahoo.com

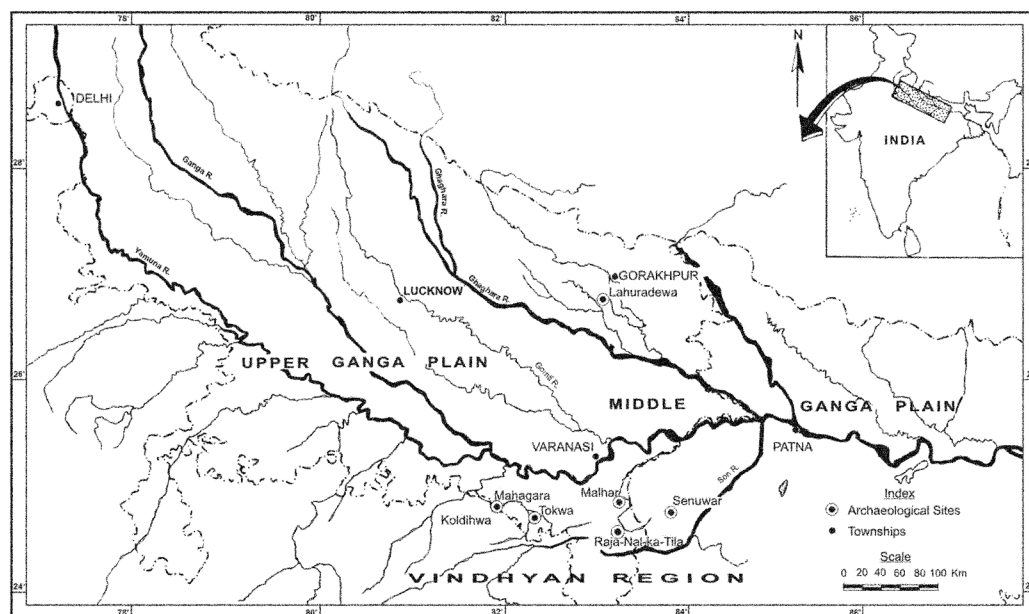


Figure 1. Map showing archaeological sites discussed in the text (after Tewari⁵⁷).



Figure 2. *a*, Panoramic view of the Tokwa archaeological site. *b*, General layout of trenches for excavation.

Table 1. ¹⁴C radiocarbon dates of charcoal samples from Tokwa

Trench	Depth (cm)	Layer	Lab no. BSIP	¹⁴ C date (yrs BP)	Calibrated date (BP)	Calibrated date (BC)
I-8	243–253	16	BS-2370	3300 ± 80	3635–3414	1685–1464
H-8	300–330	14	BS-2369	6850 ± 200	7926–7511	5976–5561
H-8	220–225	12A	BS-2054	3410 ± 70	3810–3572	1860–1622

Measurements: *L* (4.00–5.40) 4.70 × *B* (2.00–2.50) 2.30 × *T* (1.40–2.00) 1.85 mm.

Indices: $L/B = 2.04$ mm, $L/T = 2.54$ mm, $B/T = 1.24$ mm.

Morphologically, they compare well with the grains of cultivated form of rice (*O. sativa*). However, bold grains of some perennial and annual species of wild and weedy rice are also similar; thus the definite identification of *O. sativa* on the basis of grains without husk may be sus-

pect. Therefore, the husk impressions of rice on potsherds and burnt-mudclods were collected to study the pattern of epidermal tissue of lemma and palea (glumes). The granules displayed a chess-board pattern under low magnification, leaving fine streaks or slits between their alignment in rows. Under high magnification, the granules in the husk impression appeared somewhat cubicular in shape and showed sharp alignment in anastomosing and horizontal wavy rows. These features noticeable in the glumes

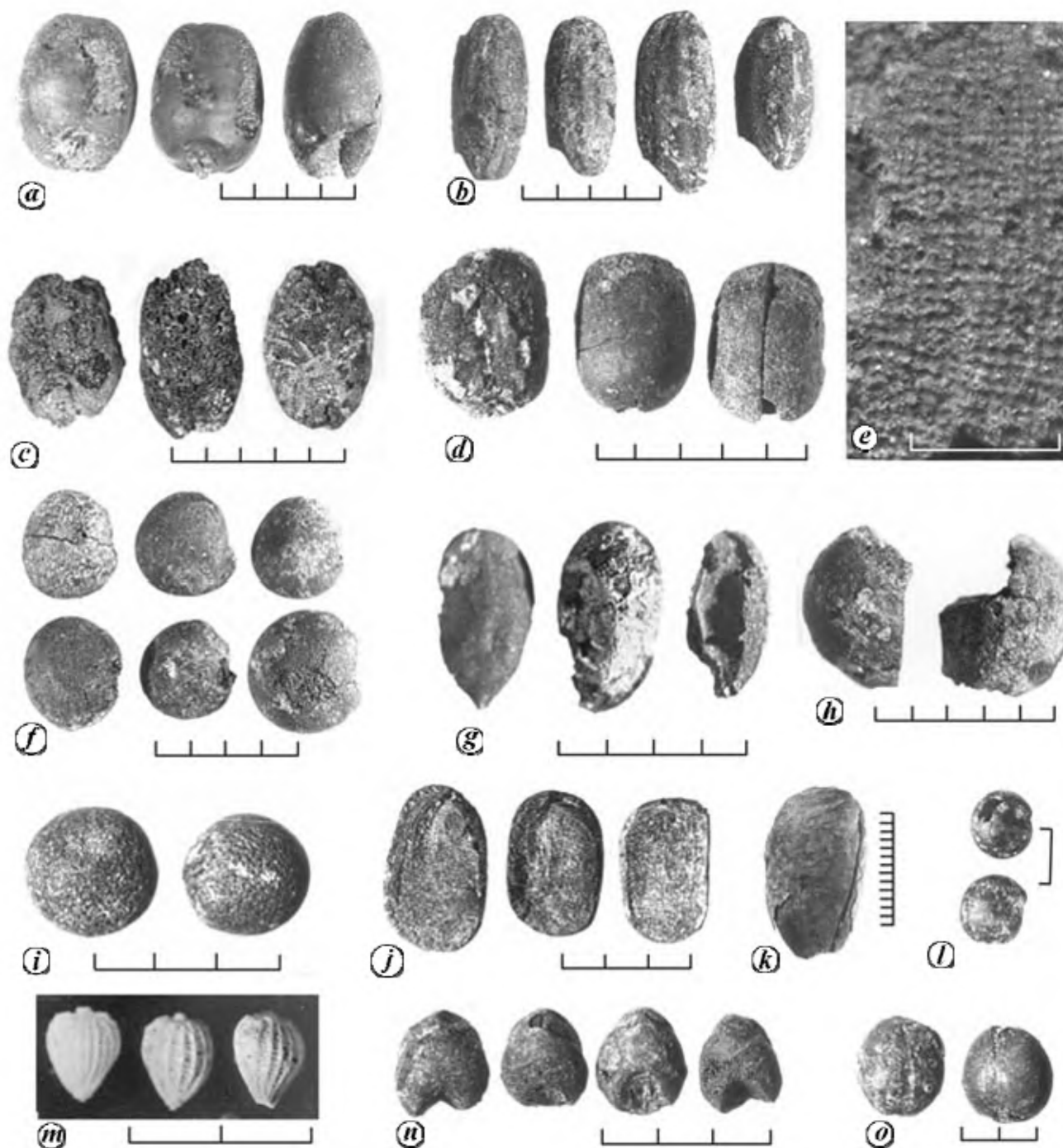


Figure 3. *a*, *Triticum aestivum* (bread wheat); *b*, *Oryza sativa* (rice); *c*, *Hordeum vulgare* (hulled barley); *d*, *Vigna radiata* (green gram); *e*, *Oryza* husk impression; *f*, *Lens culinaris* (lentil); *g*, *Linum usitatissimum* (linseed); *h*, *Pisum arvense* (field pea); *i*, *Brassica juncea* (Indian mustard); *j*, *V. radiata* (cotyledons); *k*, *Annona cf. squamosa* (custard apple); *l*, *Chenopodium album* (goosefoot); *m*, *Fimbristylis* sp.; *n*, *Setaria cf. glauca* (foxtail grass); *o*, *Vicia sativa* (common vetch).

of a number of cultivated forms of *O. sativa*, have been advantageous to refer the carbonized grains to some cultivated form of rice.

Triticum cf. aestivum L. (bread wheat, Figure 3 *a*): Nine grains were segregated and they elongate and relatively narrower towards both the ends. The thickest portion was

in the middle as well as near the embryo. Dorsal side was flattish to somewhat rounded. Therefore, on the basis of shape and other morphological features, the grains closely compared to those of bread wheat (*Triticum aestivum*).

Measurements: L (4.30–4.70) 4.50 \times B (3.00–3.50) 3.25 \times T (2.00–2.60) 2.30 mm.

Indices: $L/B = 1.38$ mm, $L/T = 1.95$ mm, $B/T = 1.41$ mm.

Hordeum vulgare L. emend. Bowden (six-rowed hulled barley, Figure 3c): Thirty-five elongated grains, tapering towards the apex and with a widening ventral furrow were encountered. Some of the grains showed traces of longitudinal ridges along the flanks and the shallow ventral-furrow caused by lost husk. Since some of the grains were partly asymmetrical or showed slight ventro-lateral twist, barley was identified as the six-rowed hulled type.

Measurements: L (4.50–5.00) $4.70 \times B$ (3.00–3.70) $3.35 \times T$ (2.00–2.50) 2.25 mm.

Indices: $L/B = 1.40$ mm, $L/T = 1.48$ mm, $B/T = 1.48$ mm.

Lens culinaris Maedik. (lentil, Figure 3f): There were twenty-two leguminous seeds, circular and flattened with keeled margins and appeared lenticular in shape. Hilum was small and lanceolate. In shape and size, the carbonized seeds are comparable to those of *L. culinaris*.

Measurements: 2.50–3.00 mm in diameter.

Pisum arvense L., syn. *P. sativum* var. *arvense* (L.) Poir (field pea, figure 3h): Two broken-pieces have been recorded. Seed coat seemed blurred and rubbed-off at places. Morphologically comparable to *P. arvense*.

Vigna radiata (L.) Wilczek (Green gram, Figure 3d and j): The lot comprised 69 complete seeds and cotyledons. Seeds were somewhat cylindrical, with rounded to angular ends. Elliptical hilum was about 1.00 mm long and evenly flat on the surface of seed coat.

Measurements (complete seeds): L (3.30–3.75) $3.52 \times B$ (2.25–3.00) $2.62 \times T$ (2.00–3.00) 2.50 mm.

Indices: $L/B = 1.34$ mm, $L/T = 1.44$ mm, $B/T = 1.04$ mm.

Brassica cf. *juncea* (L.) Czern and Coss. (Indian mustard, Figure 3i): Five oleiferous seeds exhibiting six-sided polygonal areas forming a characteristic reticulum on the surface were identified. Seeds were compared with similar seeds of *Brassica oleracea* L., *B. rapa* L., *B. napus* L., *B. juncea* (L.) Czern and Coss, *B. nigra* Koch, and cultivars of *B. campestris*. *B. oleracea* and *B. napus* have no polygonal reticulations. Reticulations were five-sided in *B. campestris* var. *toria*, 5–6-sided in *B. nigra*, 6–7-sided in *B. rapa*, seven-sided in *B. campestris* var. *sarson* and six-sided in *B. campestris* var. *dichotoma* and *B. juncea*⁵. Seed samples from this site having strictly six-sided reticulations may belong to either of these two forms. The cultivation of *B. juncea* goes back to the Harappan times⁶. Therefore, the ancient *Brassica* seeds from Tokwa have tentatively been referred to *Brassica* cf. *juncea*.

Measurements: 1.90–2.10 mm in diameter.

Linum usitatissimum L. (linseed/flax, Figure 3g): Three elongated, partly broken seeds, relatively narrower at one end have been identified.

Measurements: L (3.50–4.00) $\times B$ (2.00–2.50) $\times T$ (1.20) mm.

Annona cf. *squamosa* L. (custard apple, Figure 3k): Single, complete and some half broken seeds were recovered from the Neolithic phase. Complete seed, smooth and oblong resembled those of *A. cf. squamosa*. The characteristic ruminant endosperm was also noticeable in single half-split seeds.

Measurement: L (17.00) $\times B$ (10.00) $\times T$ (6.00) mm.

Vicia sativa L. (common vetch, Figure 3o): In all 25 seeds, more or less globular to somewhat cubicular were identified, measuring 1.90–2.10 mm in diameter. Small, ovate hilum raised along the median groove. These seeds are comparable to those of *V. sativa*.

Setaria cf. *glauca* (L.) P. Beauv. (foxtail grass, Figure 3n): Grains ovoid to somewhat oblong with narrow upper end, dorsal side curved. Hilum conspicuously broad and occasionally covered up to half length of the grains. The grains are comparable to those of *S. cf. glauca*.

Measurements: L (1.50–1.90) $\times B$ (1.50–1.70) mm.

Chenopodium album L. (goosefoot/bathua, Figure 3l): Circular and compressed-lenticular seeds with rounded margins and a characteristic marginal notch, measuring 1.00–1.20 mm in diameter. They are comparable to the seeds of *C. album*.

Fimbristylis sp. Vahl. (Figure 3m): Nuts orbicular to ovate, stalked and measuring about 0.90–1.00 \times 0.80–1.00 mm in size ($L \times B$). Nuts comprise 7–8 longitudinal rows of quadrate, hexagonal surface cells on each face. This is a large genus of annual or perennial sedges, found throughout the warmer regions of the world⁷. About 60 species are reported from India, most of them occurring as weeds in marshes, moist soils and rice fields, particularly during the monsoon season. These have, therefore, been referred to *Fimbristylis* sp.

The palaeoethnobotanical records from this study provide direct evidence of the apparent plant food staples of the Neolithic settlers at Tokwa, and reveal affinities with other agricultural settlements in the Vindhyan region and outside. The remains of crop plants of diverse origins are demonstrative of the practice of rotation of crops. These remains, however, represented in scanty amounts and being highly burnt and distorted, are likely to have resulted from certain human activities. Limitations in the data are inevitable, as they have survived the preservation by charring. A good number would have unlikely come in contact with fire and failed to appear in the record. The remains retrieved from Tokwa thus represent a small fraction of plant resources utilized by the ancient settlers. The cereals in the collection comprise hulled barley, bread wheat and rice. Leguminous crops in the collection

RESEARCH COMMUNICATIONS

Table 2. Record of field-crops from Tokwa and other archaeological sites in the Vindhyan region

Taxa	Koldihwa (6500– 1500 BC)	Mahagara (2200– 1800 BC)	Tokwa (3rd–2nd millennium BC?)	Senuwar (2200– 700/600 BC)	Malhar (1900– 800 BC)	Raja-Nal-ka-tila (1600– 700 BC)
<i>Oryza sativa</i> L. (cultivated rice)	N	N	N, C	N, NC, C	PI, EI	PI, EI
<i>Hordeum vulgare</i> L. emend. Bowden (hulled barley)		N	N, C	N, NC, C	PI, EI	PI, EI
<i>Triticum aestivum</i> L. emend. Thell. (bread wheat)			N, C	NC, C	PI, EI	PI, EI
<i>Triticum sphaerococcum</i> Perc. (dwarf wheat)				N, NC, C	PI, EI	PI, EI
<i>Sorghum bicolor</i> (L.) Moench (jowar millet)				N, NC, C	EI	EI
<i>Eleusine coracana</i> (L.) Gaertn. (ragi millet)				N	EI	PI, EI
<i>Setaria italica</i> (L.) P. Beauv. (Italian millet)					PI	PI
<i>Paspalum scrobiculatum</i> L. (Kodon millet)				NC	EI	EI
<i>Panicum cf. miliaceum</i> L. (panic millet)						PI, EI
<i>Lens culinaris</i> Medik. (lentil)		N	N, C	N, NC, C	PI, EI	PI, EI
<i>Pisum arvense</i> (L.) Poir (field pea)			N, C	N, NC, C	PI, EI	PI, EI
<i>Lathyrus sativus</i> L. (grass pea)		N	C	N, NC, C	PI, EI	PI, EI
<i>Cicer arietinum</i> L. (chick pea)				NC, C		EI
<i>Macrotyloma uniflorum</i> (Lam.) Verdcourt (horse gram)			C	NC, C	EI	EI
<i>Vigna radiata</i> (L.) Wilczek (green gram)		N	N, C	NC, C	PI, EI	PI, EI
<i>Vigna mungo</i> (L.) Hepper (black gram)		N				
<i>Vigna unguiculata</i> (L.) Walp. (cow pea)						EI
<i>Vigna aconitifolia</i> (Jacq.) Marechal (moth bean)				C		EI
<i>Cajanus cajan</i> L. (pigeon pea)		N				
<i>Linum usitatissimum</i> L. (linseed)			N	C		EI
<i>Brassica juncea</i> L. Czern. & Coss (field brassica)			N	C		EI
<i>Carthamus tinctorius</i> L. (safflower)				C		EI
<i>Sesamum indicum</i> L. (sesame)				C	EI	EI
<i>Ricinus communis</i> L. (castor)				C		
<i>Allium cepa</i> L. (onion)						EI
<i>Citrullus lanatus</i> (Thunb.) matsumiura et Nakai (watermelon)				C		

Koldihwa²⁰ (Savithri, unpublished); Mahagara^{8,21} (Savithri, unpublished); Tokwa⁵⁸; Senuwar¹⁰; Malhar⁹; Raja-Nal-ka-tila¹³. N, Neolithic; NC, Neolithic–Chalcolithic; C, Chalcolithic; PI, Pre-Iron phase; EI, Early-Iron phase.

are represented by the seeds of lentil, field pea and green gram. Oleiferous crops are represented by the seeds of Indian mustard and linseed.

Rice and green gram of Indian origin were grown during the warm rainy season. Barley, bread wheat, field pea, lentil and linseed, of Near-Eastern Complex, and Indian mustard of Indian origin were grown during winter season. Similar state of agriculture has also been recognized from other sites in the Vindhyan region and beyond (Table 2) during Neolithic, followed by transitional Neolithic–Chalcolithic, Chalcolithic and Iron Age cultures^{8–13}.

The earliest find of rice dating back to 7–6th millennia BC has been reported from the Neolithic sites of Koldihwa and Mahagara in this region¹⁴. However, this date is questionable^{15–19}. Pottery from Koldihwa and Mahagara was reported to contain copious impressions of cultivated rice (*O. sativa*), along with those of annual and perennial forms of wild rice, viz. *O. nivara* and *O. rufipogon*. Also, grains of *O. sativa* were recovered from Mahagara²⁰ (Savithri, unpublished; Sharma, unpublished). Reports of barley from the same stratum at Mahagara²¹, from which domesticated rice was recorded to establish rice-based agriculture during the 7–6th millennia BC, brought its authenticity under question²². Barley, which was a staple crop of the Harappans in northwestern India, would cer-

tainly have not arrived in this region before the Harappan times. Only fresh excavations with a series of dates will resolve the quandary regarding the beginning of agriculture in early Holocene in the Belan Valley. Recent studies on the botanical remains from Malhar, District Chandauli and Lahuradewa, District Sant Kabir Nagar^{9,23} dispel all doubts regarding early agriculture in the Vindhyas and Ganga Plain, and support the contributions made by the Allahabad University, in establishing the primacy of early Neolithic beginning in the Belan Valley, in the Indian archaeological context.

Diffusion of barley, wheat, lentil and field pea, which are crops of Harappan nutritional trait in northern and northwestern India, into the rice-growing zone is worthwhile to draw meaningful conclusion in terms of direct or indirect relationships of Neolithic people in the Vindhyan region with some other cultural communities practising cultivation of these crops^{10,24}. Further, the find of cultivated rice (*O. sativa*) of northeastern and eastern India (Gangetic Plain) in the food economy of early and mature Harappans is equally important to discuss far distant movement of different cultural groups^{25,26}. We still need to know what sort of cultural network led the widespread diffusion of Harappan crops in the Vindhyan region and adjoining areas and vice versa, and how it took place at

such an early date. The fact is intricate and its justification may lie in a combination of causes. It may create considerable curiosity amongst archaeologists to know the flow of ideas and economic traits in such a wide area, through diverse cultural zones. Empirical study of data produced by archaeological excavations at Senuwar, Malhar and Raja-Nala-ka-tila in the Vindhyan region during Neolithic, Chalcolithic and Early Iron Age levels, confirms through botanical remains that, the Harappans during much earlier times had substantial influence in the agricultural developments of distant areas in the east and in the spread of new crops, which were principal founder crops in the Harappan economy^{9,10,13}. This new cropping system might have not been accepted merely for the reason that it became available somewhere through contact, but would have also been desirable and advantageous to them in their ecological conditions. The factual remains of foodgrains of Harappan traits encountered in the Neolithic deposits at Tokwa suggest the stage when these crops became an essential economic staple. The plants and cultural data are not only complementary, but absolutely interdependent for interpretation purpose.

Only a few weeds have been encountered from Tokwa, along with the foodgrains, in comparison to other sites in the region. *V. sativa* occurs as the most frequent weed in the pulse crops. It is a forage legume of rich protein value, consumed by cattle and is also used as hay. This species spread in the Indian region from Europe, through the north temperate zone in the Old World. *Setaria* cf. *glauca* may have played an important role in the subsistence economy of Tokwa settlers. This is the commonest species of foxtail grass in the region, occurring in grasslands, self-sown and sometimes cultivated also as a kharif crop on uplands or hilly regions^{27,28}. In all probability this species would have been a common component in the diet of people in the past.

C. album is common in moist places and occurs as a weed in the cold season field crops. It is eaten as a vegetable. *Fimbristylis* sp. occurs as weeds in marshes, moist soils and rice fields, particularly during monsoon season.

Fortuitously, the most important find from the Neolithic deposit (trench-H8; layer-12A; depth 2.20–2.25 m) dated to 1740 BC, is the seed of South American custard apple. The occurrence of custard apple in the form of fruit coat has been recorded from Sanghol, Punjab during the Kushana times (AD 100–300); seeds from Raja-Nala-ka-tila in Sonbhadra District, UP dated to 740 BC and now from Neolithic Tokwa^{13,29}. In the light of our present botanical knowledge, the species of *Annona* are of American origin. An Indian origin of custard apple is discounted; it has certainly been regarded to have been introduced in the East by the Portuguese in the 16th century AD^{30–32}. Mehra³¹ contributed valuable information on the Portuguese introduction of fruit plants in India. According to him, three species have been introduced into India and the terms custard apple, bullock's heart and

sweet sop have been so indiscriminately used in India, that it is hardly possible to use them with accuracy. However, the name custard apple, to which the specimens from Tokwa and other sites belong, refers to *Annona squamosa*. Cunningham⁴³ has described a number of trees and fruits from varied sculptures of Bharhut and Mathura, and identified *A. squamosa* among them. However, his identification was contested on the ground that the tree was first introduced in India by the Portuguese. The original stupas were constructed in the middle of 3rd century BC. The Sanchi gateways were constructed in the last quarter of the 1st century BC⁴⁴. Sitholey⁴⁵ did monumental work on the plants represented in the Bharhut and Sanchi sculptures and identified 40 plants. With the help of free-drawings, he attempted the identification of plants portrayed in a style which is partly conventional and partly realistic. The dazzling presence of custard apple has been confirmed by him, as claimed by Cunningham⁴³.

Interestingly, archaeological evidences of Mexican maize in India have further strengthened the pre-Columbian introduction. Potsherds with maize impressions from Kaundinyapura, Maharashtra have been dated to the Muslim period about AD 1435. Another evidence for the presence of maize in India prior to the traditional European contact can be found in stone sculptures of maize ears in the 12th and 13th century AD Hoysala temples in Karnataka. The ears show the morphology of maize in such intricate and specifically variable representations, that it would have been impossible for sculptors to have imagined the variability consistently and realistically, without having a large number of actual maize ears as models⁴⁶. The tradition among Nahua Indians of Mexico was to sculpt maize ears with perfection to attain closeness to reality in the headdress of the Goddess Chicomecoatl⁴⁷ and other archaeological representations in the Americas⁴⁸. It may not be ruled out that such a tradition of sculpting could have been carried to India, along with the introduction of maize.

Sachan *et al.*⁴⁹ and Sachan and Sarkar^{50,51} have reported that the multi-eared Sikkim primitive popcorn shows a distinct constitutive heterochromatic phenomenon similar to that found in South American maize. Therefore, some ancient maizes have likely existed in Asia for a long time.

The archaeobotanical record of beans of American origin, such as kidney bean or common bean (*Phaseolus vulgaris*), sierra bean (*Phaseolus lunatus*) and phasemy bean (*Phaseolus lathyroides*) from the proto-historic sites in peninsular India⁵² and a weed Mexican poppy (*Argemone mexicana*) from Narhan, Gorakhpur, UP dated to 1060–1100 BC⁵⁵ and Sanghol, Punjab during Kushana times dated²⁹ to AD 100–300, are suggestive of the possibility of custard apple and other economically important plants being grown in much earlier times before the arrival of the Portuguese in India.

Evidences of crop plants like American beans and maize are supportive for an early pre-Columbian introduction of

American plants. It would be surprising if custard apple would not have been among these plants.

Although the archaeobotanical records are rare and spotty, the contribution from SE Asian cultures to the rest of the world may prove to be overwhelming⁵⁴. A series of caves in Timor, Indonesia have continuous sequence of occupation from 12,000 BC to the time of Christ^{55,56}. Interestingly, in the top layer several introduced New World crops occur, such as peanuts, custard apple and maize together with SE Asian or generally Asian natives. It is a matter of chance that factual evidences of custard apple have been found from three archaeological sites in the Indian subcontinent. Botanical data have not yet been systematically discovered, but reports give enough indication that botanical investigations bare great potential.

The studies of plant remains have brought to light an insight into the glimpses of economic exploitation of vegetational resources by the ancient inhabitants at Tokwa, in the vicinity of Vindhyan region. Agriculture was their rewarding economy.

- Misra, V. D., Pal, J. N. and Gupta, M. C., Excavation at Tokwa: A Neolithic-Chalcolithic settlement. *Pragdhara*, 2001, **11**, 59–72.
- Misra, V. D., Stone age cultures, their chronology and beginning of agriculture in the north-central India, An Annual Conference of India Society for Prehistoric and Quaternary Studies, Gwalior, 2006.
- Tewari, R., Srivastava, R. K., Singh, K. K., Saraswat, K. S. and Singh, I. B., Preliminary report of the excavation at Lahuradewa, District Sant Kabir Nagar, UP 2001–2002: Wider archaeological implications. *Pragdhara*, 2002–03, **13**, 37–68.
- Tewari, R., Srivastava, R. K., Singh, K. K., Vinay, R., Trivedi, R. K. and Singh, G. C., Recently excavated sites in the Ganga Plain and North Vindhyas: Some observations regarding the pre-urban context. *Pragdhara*, 2004–05, **15**, 39–50.
- Buth, G. M. and Roshan Ara, Seed coat anatomy of some cultivated Brassicas. *Phytomorphology*, 1983, **31**, 69–78.
- Mackay, E. J. H., *Chanhudaro Excavations-1935–36*, American Oriental Series 20, American Oriental Society, New Haven, 1943.
- Anon., *The Wealth of India: Raw Materials*, Vol. IV:F–G. CSIR, New Delhi, 1956.
- Emma, H. L. and Fuller, D. Q., Investigating crop processing using phytolith analysis: The example of rice and millets. *J. Archaeol. Sci.*, 2005, **32**, 739–752.
- Saraswat, K. S., Plant economy in ancient Malhar. *Pragdhara*, 2003–04, **14**, 137–171.
- Saraswat, K. S., Plant economy of early farming communities. In *Early Farming Communities of the Kaimur* (ed. Singh, B. P.), Publication Scheme, Jaipur, 2004, vol. II, pp. 416–535.
- Vishnu-Mittre, Neolithic plant economy at Chirand. *Palaeobotanist*, 1972, **21**, 18–22.
- Srivastava, C., Seed and fruit remains from ancient Manjhi, District Saran, Bihar. *Pragdhara*, 2000–01, **11**, 141–153.
- Saraswat, K. S. and Pokharia, A. K., Annual Report, BSIP, Lucknow, 2002–03.
- Sharma, G. R., Misra, V. D., Mandal, D., Misra, B. B. and Pal, J. N., *Beginnings of Agriculture (Epi-Palaeolithic to Neolithic: Excavations at Chopani-Mando, Mahadaha and Mahagara)*, Abinash Prakashan, Allahabad, 1980.
- Possehl, G. L. and Rissman, P. C., The chronology of prehistoric India: From earliest times to the Iron Age. In *Chronologies in Old World Archaeology* (ed. Ehrich, R. W.), Chicago, 1992, vol. 1, pp. 465–490.
- Pal, J. N., *Archaeology of Southern Uttar Pradesh – Ceramic Industries of Northern Vindhyas*, Swabha Prakashan, Allahabad, 1986.
- Fuller, D. Q., Fifty years of archaeobotanical studies in India: Laying a solid foundation. In *Indian Archaeology in Retrospect: Archaeology and Interactive Disciplines* (eds Settar, S. and Korisettar, R.), ICHR, Manohar, 2002, vol. III, pp. 247–364.
- Singh, P., The Neolithic cultures of northern and eastern India. In *Prehistory: Archaeology of South Asia* (eds Settar, S. and Korisettar, R.), Indian Archaeology in Retrospect, ICHR, Manohar, 2002, vol. I, pp. 127–150.
- Glover, I. C. and Higham, C. F. W., New evidence for early rice cultivation in South, Southeast and East Asia. In *The Origins and Spread of Agriculture and Pastoralism in Eurasia* (ed. Harris, D. R.), UCL Press, London, 1996, pp. 413–441.
- Sharma, G. R., From hunting and food gathering to domestication of plants and animals in the Belan and Ganga Valleys. In *Recent Advances in Indo-Pacific Prehistory* (eds Misra, V. N. and Bellwood, P.), Oxford & IBH, New Delhi, 1985, pp. 369–371.
- Dixit, A. S., Oldest Neolithic barley from India. *Natl. Acad. Sci. Lett.*, 1987, **10**, 125–127.
- Saraswat, K. S., Archaeobotanical remains in ancient cultural and socio-economic dynamics of the Indian subcontinent. *Palaeobotanist*, 1992, **40**, 514–545.
- Saraswat, K. S. and Pokharia, A. K., Plant economy at Lahuradewa: A preliminary contemplation (Abst.). In Joint Annual Conference: IAS, ISPQS and IHCS, Lucknow, 28–31 December 2004, pp. 46–47.
- Saraswat, K. S., Agricultural background of the early farming communities in the Middle Ganga Plain. *Pragdhara*, 2004–05, **15**, 145–177.
- Saraswat, K. S. and Pokharia, A. K., Harappan plant economy at ancient Balu, Haryana. *Pragdhara*, 2001–02, **12**, 153–171.
- Saraswat, K. S. and Pokharia, A. K., Palaeoethnobotanical investigations at ancient Balu, Haryana. *Pragdhara*, 2002–03, **13**, 105–139.
- Haines, H. H., *The Botany of Bihar and Orissa, Part-I*. Adlard & Sons and West Newman Ltd, London, 1925 (reprinted 1978, Bishen Singh Mahendra Pal Singh, Dehra Dun).
- Anon., *The Wealth of India: Raw Materials*, Vol. IX (Rh–So), CSIR, New Delhi, 1972.
- Pokharia, A. K. and Saraswat, K. S., Plant economy during Kushana period (100–300 AD) at ancient Sanghol, Punjab. *Pragdhara*, 1998–99, **9**, 75–121.
- Watt, G., *A Dictionary of the Economic Products of India*, Calcutta, 1889, vol. I, pp. 259–260.
- Mehra, K. L., Portuguese introduction of fruit plants in India. *Indian Hort.*, 1965.
- Kapil, R. N., Biology in ancient and medieval India. *Indian J. Hist. Sci.*, 1970, **5**, 119–140.
- Randhawa, M. S., *A History of Agriculture-3*, ICAR, New Delhi, 1983.
- Hooker, J. D., *The Flora of British India. Vol. 1: Ranunculaceae to Sapindaceae*. Royal Gardens, Kew, 1872 (reprinted 1973, Bishen Singh Mahendra Pal Singh, Dehra Dun and Periodical Experts, Delhi).
- Brandis, D., *The Forest Flora of North-West and Central India*, The Royal Gardens, Kew, 1874 (reprinted, Bishen Singh Mahendra Pal Singh, Dehra Dun).
- DeCandolle, A., *Origin of Cultivated Plants*, Hafner Publishing Co, New York, 1959, pp. 168–176.
- Gamble, J. S., *A Manual of Indian timbers*, 1902 (reprinted 1972, Bishen Singh Mahendra Pal Singh, Dehra Dun).
- Yule, H. and Burnell, A. C., *Hobson–Jobson: Anglo-Indian Dictionary*, London, 1886 (second edn, ed. Crooke, W.), London, 1903 (taken from Mehra, 1965).

39. Venkataratnam, L., The custard-apple and allied fruits. In *Fruit Culture in India* (eds Singh, S., Krishnamurthi, S. and Katyal, S. L.), ICAR, New Delhi, 1963, pp. 239–246.
40. Good, R., *The Geography of Flowering Plants*, Longman Group Ltd, London, 1974, 4th edn.
41. Smith, P. M., Minor crops. In *Evolution of Crop Plants* (ed. Simmonds, N. W.), Longman, London, 1976, p. 302.
42. Ambasta, S. P., Ramachandran, K., Kashyap, K. and Chand, R., *The Useful Plants in India*, CSIR, New Delhi, 1986.
43. Cunningham, A., *The Stupa of Bharhut*, London, 1879 (reprinted 1962, Indological Book House, Varanasi).
44. Brown, P., *Indian Architecture (Buddhist and Hindu Periods)*, D. B. Taraporevala Sons and Co, Bombay, 1949, 2nd edn.
45. Sitholey, R. V., Plants represented in ancient Indian sculpture. *Geophytology*, 1976, **6**, 15–26.
46. Johannessen, C. L. and Parker, A. Z., Maize ears sculptured in 12th and 13th century AD, India as indicator of pre-Columbian diffusion. *Econ. Bot.*, 1989, **43**, 164–180.
47. Anton, F., *Women in Pre-Columbian America*, Abner Schram, New York, 1973.
48. Mangelsdorf, P. C., *Corn: Its Origin, Evolution and Improvement*, Belknap Press, Harvard University, Cambridge, 1974.
49. Sachan, J. K. S., Sarkar, K. R. and Payak, M. M., Studies on distribution of constitutive heterochromatin in relation to origin, evolution and diffusion of maize. In *Advances in Cytogenetics and Crop Improvement*, Kalyani Publishers, New Delhi, 1982, pp. 41–48.
50. Sachan, J. K. S. and Sarkar, K. R., Sikkim primitive maize – An overview. *Indian J. Genet. Plant Breed. (Suppl.)*, 1986, **46**, 153–161.
51. Sachan, J. K. S. and Sarkar, K. R., Discovery of Sikkim primitive precursor in the Americas. *Maize Genet. Coop., Newsl.*, 1986, **60**, 104–106.
52. Vishnu-Mittre, Sharma, A. and Chanchala, S., Ancient plant economy at Daimabad. In *Daimabad (1976–77)* (ed. Sali, S. A.), MASI: ASI, New Delhi, 1986, vol. 83, pp. 588–627.
53. Saraswat, K. S., Sharma, N. K. and Saini, D. C., Plant economy at ancient Narhan. In *Excavations at Narhan (1984–89)* (ed. Singh, P.), Department of Ancient Indian History, Culture and Archaeology, BHU, Varanasi and BR Publishing Corp., Delhi, 1994, pp. 255–346.
54. Solheim II, W. G., Northern Thailand, Southeast Asia and world prehistory. *Asian Perspect.*, 1970, **XIII**, 145–162.
55. Glover, I. C., Excavation in Timor (2 vols.) Ph D thesis, Australian National University, Canberra, 1972.
56. Glover, I. C., The Late Stone Age in eastern Indonesia. *World Archaeol.*, 1977, **9**, 420–461.
57. Tewari, R., The myth of dense forests and human occupation in the Ganga Plain. *Man Environ.*, 2004, **XXIX**, 102–116.
58. Pokharia, A. K., Annual Report, 2005–06, BSIP, Lucknow.

ACKNOWLEDGEMENTS. I am grateful to Dr N. C. Mehrotra, Director, BSIP, Lucknow for encouragement and also for providing facilities to accomplish this work. I also thank Drs V. D. Misra, J. N. Pal and M. C. Gupta, Department of Ancient History, Culture and Archaeology, Allahabad University, Allahabad, for providing materials collected earlier and also for the opportunity to collect botanical remains during the course of excavation in 2003.

Received 9 April 2007; revised accepted 7 November 2007

Assessing the applicability of $\delta^{18}\text{O}$ *Globigerina bulloides* to estimate palaeotemperature from the southwestern Indian Ocean

N. Khare¹, R. Saraswat^{2,*} and S. K. Chaturvedi¹

¹National Centre for Antarctic and Ocean Research, Headland Sada, Vasco-da-Gama, Goa 403 804, India

²Centre for Advanced Studies, Department of Geology, University of Delhi, Delhi 110 007, India

Modern sea-water temperature has been estimated using oxygen isotopic composition of planktic foraminiferal species, *Globigerina bulloides* recovered from the surface sediments collected from southwestern Indian Ocean (IO). The sea-water temperature estimated from $\delta^{18}\text{O}$ *G. bulloides* has been compared with that measured on-board. Though a nearly constant offset is noticed between estimated and measured sea-water temperatures at locations south of 15°S latitude, the general trend is at tandem. The coherence between estimated and measured sea-water temperatures indicates that the $\delta^{18}\text{O}$ *G. bulloides* palaeotemperature equation derived from laboratory culture experiments can be applied to infer past sea-water temperature variations from southwestern IO.

Keywords: *Globigerina bulloides*, palaeotemperature, sea water, southwestern Indian Ocean.

SEA-SURFACE temperature (SST) is an important climatic parameter. A slight change in SST leads to enormous change in the rainfall pattern and intensity^{1,2}. Increasing intensity and frequency of storms has also been attributed to the increasing global temperature^{3,4}. SST mainly varies in response to changes in the solar irradiance^{5,6}. However, the historic abrupt increase in SST has been attributed to anthropogenic influence on the global climatic variations⁷. Understanding the temperature variability during geologic past can help in deciphering human contribution to the recent abrupt increase in global temperature⁸. Various techniques such as faunal transfer functions^{9,10}, alkenone unsaturation ratios^{11,12} and artificial neural network (ANN) analyses of planktic foraminifera¹³, assemblage, morphological characteristics and shell chemistry of foraminifera, have been used to decipher past SST from the world oceans^{9,14–16}.

In view of the experimental evidence of temperature control on oxygen isotopic composition of the carbonate^{17,18}, extensive oxygen isotopic studies have been carried out on marine microorganisms, especially foraminifera, to decipher past sea-water temperature changes^{19,20}. Though, in the beginning, the total change in oxygen isotopic composition of the foraminiferal shells was attributed to

*For correspondence. (e-mail: rs.niog@gmail.com)