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

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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 2 *a* 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 triangle[1]. 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, oilseeds 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, Jhusi[2] 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 floatation 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 3 *b* 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.

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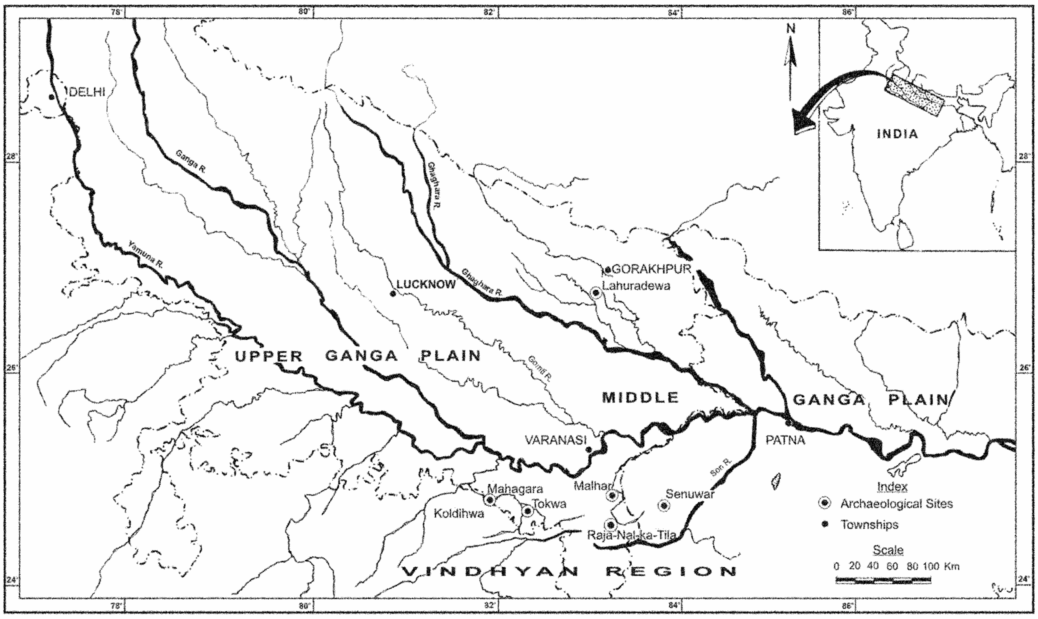

Figure 1. Map showing archaeological sites discussed in the text (after Tewari[57]).

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

Table 1. ^{14}C 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 suspect. 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 anastamozing and horizontal wavy rows. These features noticeable in the glumes

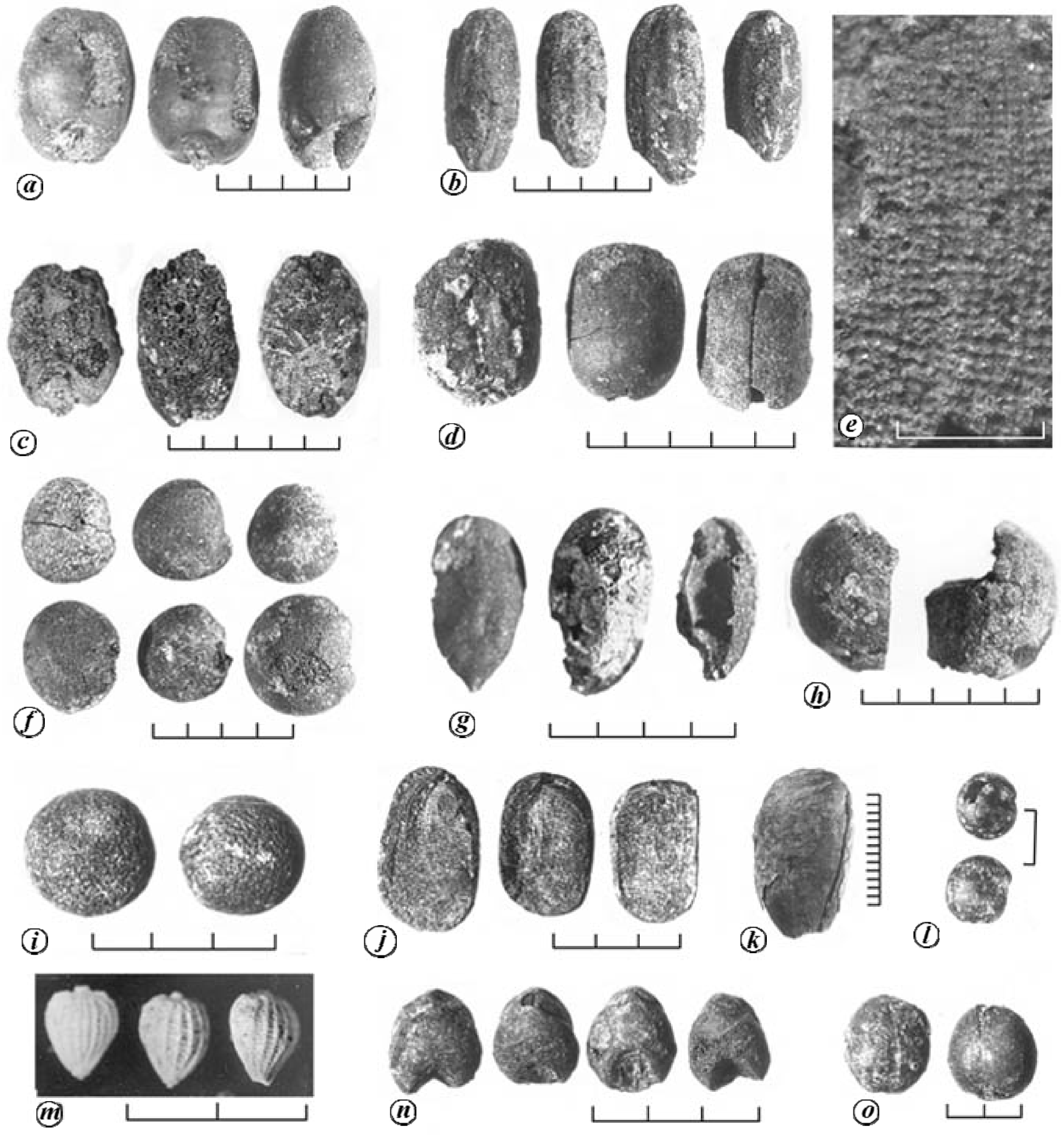

Figure 3. ***a***, *Triticum aestivum* (bread wheat); ***b***, *Oryza sativa* (rice); ***c***, *Hordeum vulgare* (hulled barley); ***d***, *Vigna radiata* (green gram); ***e***, *Oryza* husk impression; ***f***, *Lens culinaris* (lentil); ***g***, *Linum usitatissimum* (linseed); ***h***, *Pisum arvense* (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 × B (3.00–3.50) 3.25 × 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 3 *c*): 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 × B (3.00–3.70) 3.35 × 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 3 *f*): 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 3 *h*): 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 3 *d* 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 × B (2.25–3.00) 2.62 × 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 3 *i*): 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 cultigens 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 times[6]. 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 3 *g*): Three elongated, partly broken seeds, relatively narrower at one end have been identified.

Measurements: L (3.50–4.00) × B (2.00–2.50) × T (1.20) mm.

Annona cf. *squamosa* L. (custard apple, Figure 3 *k*): 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 ruminate endosperm was also noticeable in single half-split seeds.

Measurement: L (17.00) × B (10.00) × T (6.00) mm.

Vicia sativa L. (common vetch, Figure 3 *o*): 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 grove. These seeds are comparable to those of *V. sativa.*

Setaria cf. *glauca* (L.) P. Beauv. (foxtail grass, Figure 3 *n*): 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) × B (1.50–1.70) mm.

Chenopodium album L. (goosefoot/bathua, Figure 3 *l*): 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 3 *m*): Nuts orbicular to ovate, stalked and measuring about 0.90–1.00 × 0.80–1.00 mm in size (L × 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 world[7]. 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 ancients settlers. The cereals in the collection comprise hulled barley, bread wheat and rice. Leguminous crops in the collection

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)
Oryza sativa L. (cultivated rice)	N	N	N, C	N, NC, C	PI, EI	PI, EI
Hordeum vulgare L. emend. Bowden (hulled barley)		N	N, C	N, NC, C	PI, EI	PI, EI
Triticum aestivum L. emend. Thell. (bread wheat)			N, C	NC, C	PI, EI	PI, EI
Triticum sphaerococcum Perc. (dwarf wheat)				N, NC, C	PI, EI	PI, EI
Sorghum bicolor (L.) Moench (jowar millet)				N, NC, C	EI	EI
Eleusine coracana (L.) Gaertn. (ragi millet)				N	EI	PI, EI
Setaria italica (L.) P. Beauv. (Italian millet)					PI	PI
Paspalum scrobiculatum L. (Kodon millet)				NC	EI	EI
Panicum cf. *miliaceum* L. (panic millet)						PI, EI
Lens culinaris Medik. (lentil)		N	N, C	N, NC, C	PI, EI	PI, EI
Pisum arvense (L.) Poir (field pea)			N, C	N, NC, C	PI, EI	PI, EI
Lathyrus sativus L. (grass pea)		N	C	N, NC, C	PI, EI	PI, EI
Cicer arietinum L. (chick pea)				NC, C		EI
Macrotyloma uniflorum (Lam.) Verdcourt (horse gram)			C	NC, C	EI	EI
Vigna radiata (L.) Wilczek (green gram)		N	N, C	NC, C	PI, EI	PI, EI
Vigna mungo (L.) Hepper (black gram)		N				
Vigna unguiculata (L.) Walp. (cow pea)						EI
Vigna aconitifolia (Jacq.) Marechal (moth bean)				C		EI
Cajanus cajan L. (pigeon pea)		N				
Linum usitatissimum L. (linseed)			N	C		EI
Brassica juncea L. Czern. & Coss (field brassica)			N	C		EI
Carthamus tinctorius L. (safflower)				C		EI
Sesamum indicum L. (sesame)				C	EI	EI
Ricinus communis L. (castor)				C		
Allium cepa L. (onion)						EI
Citrullus lanatus (Thunb.) matsumiura et Nakai (watermelon)				C		

Koldihwa[20] (Savithri, unpublished); Mahagara[8,21] (Savithri, unpublished); Tokwa[58]; Senuwar[10]; Malhar[9]; Raja-Nal-ka-tila[13].
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 region[14]. 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 Mahagara[20] (Savithri, unpublished; Sharma, unpublished). Reports of barley from the same stratum at Mahagara[21], from which domesticated rice was recorded to establish rice-based agriculture during the 7–6th millennia BC, brought its authenticity under question[22]. Barley, which was a staple crop of the Harappans in northwestern India, would certainly 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]. Mehra[31] 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*. Cunningham[43] 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 BC[44]. Sitholey[45] 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 Cunningham[43].

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 models[46]. 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 Chicomecoatl[47] and other archaeological representations in the Americas[48]. 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 (*Phaselous vulgaris*), sierra bean (*Phaseolus lunatus*) and phasemy bean (*Phaseolus lathyroides*) from the proto-historic sites in peninsular India[52] and a weed Mexican poppy (*Argemone mexicana*) from Narhan, Gorakhpur, UP dated to 1060–1100 BC[55] and Sanghol, Punjab during Kushana times dated[29] 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 overwhelming[54]. 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.

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

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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 $\delta^{18}O$ *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 $\delta^{18}O$ *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 variations[7]. Understanding the temperature variability during geologic past can help in deciphering human contribution to the recent abrupt increase in global temperature[8]. Various techniques such as faunal transfer functions[9,10], alkenone unsaturation ratios[11,12] and artificial neural network (ANN) analyses of planktic foraminifera[13], 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

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