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The Ganges on the World Neolithic map: The significance of Recent Research on Agricultural Origins in Northern India

Dorian Q. Fuller

Abstract

Recent researches, including that by the U.P. Sta.e Department of Archaeology at Lahuradewa, are providing new information relating to early farmers and late hunter-gatherers in Gangetic India. This paper attempts to situate these results in a comparative perspective of archaeobotanical research on plant domestication in other parts of the world and provide a critical appraisal of what is now known and what is less certain about the evidence from the Ganges. In particular the current state of biogeographic and genetic research on the wild ancestors of rice, strongly support independent rice domestication somewhere in northern or eastern India. There remain several challenges to actually being able to identify archaeologically the transition process from foragers gathering wild rice, to the early cultivation of rice to the subsequent morphological changes in rice which are called domesticated. Of particular importance is the complication of uneven ripening, found in wild populations and probably in early cultivated rice which calls for large scale quantitative studies on rice morphological change. Based on what is now known from the Ganges it is clear that the Neolithic transition differs in some respects from the trajectory to agriculture followed in Southwest Asia and shows some similarities, but also differences, from trajectories known from Africa and East Asia. Further work that clarifies this North Indian trajectory and considers possible causal factors, will surely augment our understanding of the evolution of human cultural and economic diversity worldwide.

Introduction

Recent multidisciplinary research at Lahuradewa is of importance for understanding important changes in the human condition in the Gangetic region and for placing this area into a global comparative framework of long-term human history. The results available so far raise as many questions as answers, which is surely a characteristic of all good scientific research. One of the key areas of investigation at the site is the origins of agriculture, or the beginnings of the Neolithic, long-recognized as a key 'revolution' in the history of human societies[1]. The present paper will explore a number of questions about the beginnings of agricultural societies in the Ganges basin that are relevant to further research at Lahuradewa and other sites, and situate these in a comparative international perspective on agricultural origins. The paper is divided into sections covering the case for independent plant domestication in northern (Gangetic) India, the serious methodological difficulties with identifying rice domestication, and a comparative consideration of the some of the different pathways that have been followed towards agriculture in different world regions (Southwest Asia, Africa, East Asia and the Americas). In the conclusion the challenge of explaining the origins of agriculture is introduced. Throughout these sections specific

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comments on Lahuradewa and suggestions about methodological issues in the investigation of agricultural origins will be raised.

The case for independent rice domestication in Gangetic India

The evidence from Lahuradewa is argued to suggest a local process of rice domestication during the middle Holocene, which, when satisfactorily demonstrated, is a significant revision of widely held views of the derivative nature of agriculture in India. Many scholars and several influential scholarly syntheses have assumed or inferred the beginnings of agriculture in India to be derived from the outside. Most archaeological syntheses of agricultural origins talk of five to seven areas of original domestication: the Near East (southwestern Asia), China, central America (southern Mexico), the Andes (Peru) and perhaps eastern North America or sub-Saharan African savannahs[2]. In general the origins of agriculture is sought in the early Holocene (or late Pleistocene) in regions that provided major staple foods of the modern world, such as maize from Mexico, rice from China, wheat from Southwest Asia or sorghum from Africa. Archaeological evidence has already overturned this emphasis on the early Holocene and on the anachronistic bias towards major world staples. It is clear that maize was domesticated towards to middle Holocene, and much later than squashes/pumpkins, a traditional subsidiary crop[3]. Also in Eastern North America cultivation of food crops is clearly documented only from the later mid-Holocene (perhaps ca. 2500 BC) and is based on species that are not important crops today and mostly extinct as cultivars[4]. There is a particularly important lesson here: archaeobotanical research can reveal early agricultural systems and plant domestications that are not paralleled or predicted from the ethnographic present. Even in Southwest Asia, which gave us wheat (actually a number of different wheat species) and barley, the early Neolithic included cultivation of some species that have dropped out of agriculture, or largely so, including a species of rye (*Secale)* and two-grained einkorn at sites in Syria[5], and a morphologically distinct wheat that was similar to but different from emmer wheat and not paralleled in any known modern wheat crop[6]. In Africa, the archaeological evidence increasingly indicates that plant cultivation is rather late, probably beginning in the third millennium BC or so[7]. As I have been arguing in recent years, evidence from Southern India suggests a similarly late (third millennium BC) but independent (based on local wild crop progenitors, and from a local cultural tradition) origins of agriculture[8]. And to some degree this is parallel to the North American case because the origins in South India is based on some species that have been marginalized (though not extinct as cultivars), namely the small millets *Brachiaria ramosa* and *Setaria verticillata*. I have also argued based on the fragmentary archaeological evidence but mainly based on biogeography of wild relatives of crops that Gangetic India is also a likely centre of independent plant domestication[9], which could also prove to be the case in Gujarat (and/or southern Rajasthan) and Orissa. Archaeobotanical evidence arguing for independent domestication, prominently including rice, has accumulated in recent years[10].

Part of the case for independent domestication in the Ganges is that, in stratigraphically sampled sites, Southwest Asian crops occur later than indigenous species. This is thoroughly documented at Senuwar, where only rice and a small millet (and job's tears, a weed?) occur in the earliest deposits of the first phases, while wheat and barley are introduced in higher deposits (but still in the first ceramic period)[11]. This is now also indicated at Lahuradewa. Similarly new flotation data from Mahagara indicates only rice and millet(s) in the earliest level at the site, recorded both in grains and phytoliths, with other crops including pulses native to South Asia, barley, wheat and lentils (native to Southwest Asia) occurring in a later stratigraphic phase[12]. All of these data argue that rice and millet cultivation was established from indigenous origins and then crops from the west were adopted into this system. Understanding this process

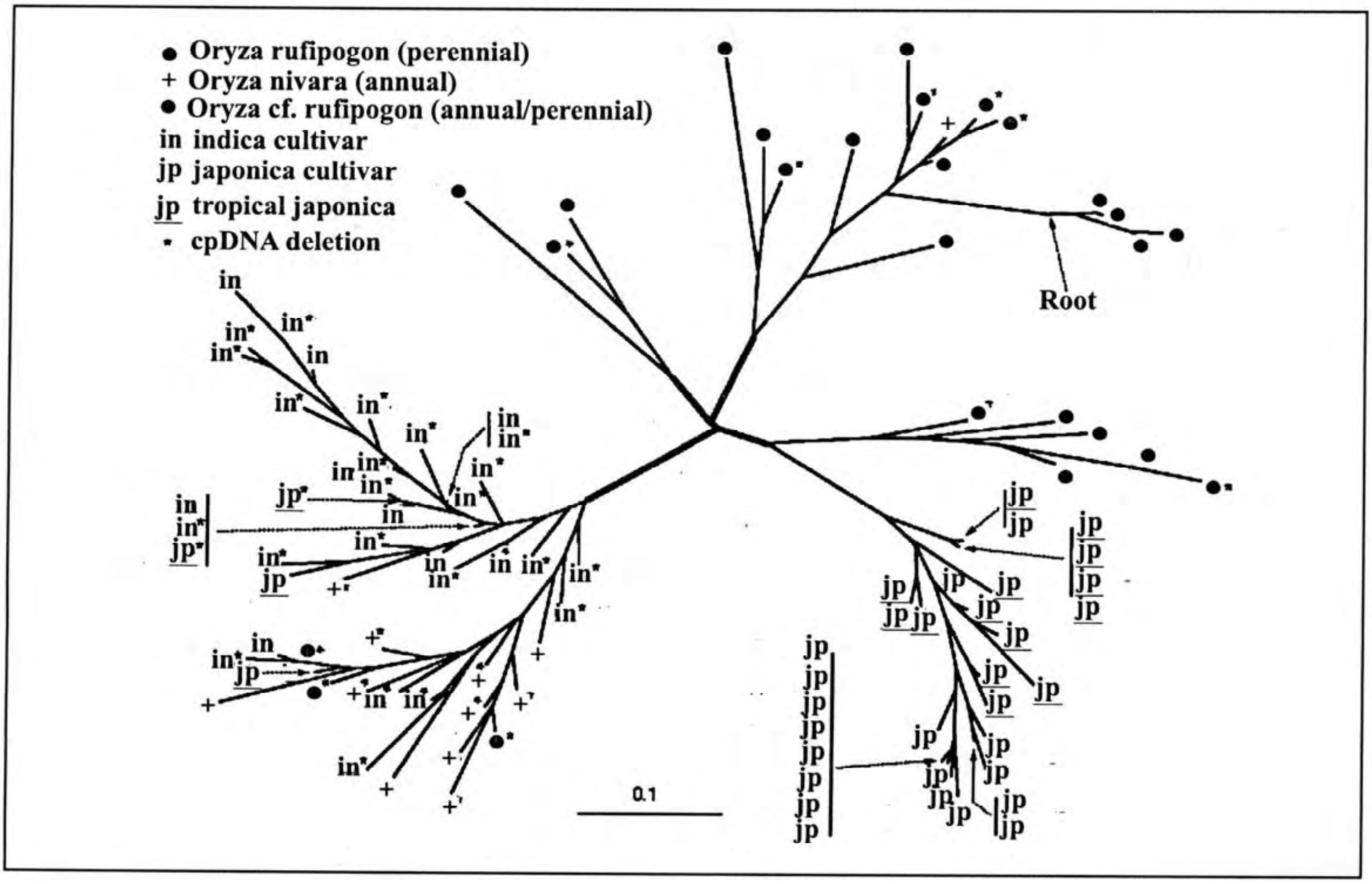

Fig. 1. A phylogenetic representation of modern rice cultivars and wild populations based on SINE genetics (after Cheng et al. 2003; taxonomy revised to follow Vaughan 1994). This shows the clearly distinct lineages of japonica (including most tropical forms, sometimes called javanica) and indica cultivars, which are interspersed with the annual wild populations (*Oryza nivara*)

of the adoption requires further research. Based on present data this process of adoption takes place rather slowly, over several centuries: direct AMS dates on barley are available from Lahuradewa[13], Damdama[14], Mahagara[15], while at Senuwar it is well-constrained stratigraphically[16]. The earliest appearance is perhaps that at Damdama closer to ca. 2400 BC, while ca. 2200 BC can be suggested for the easterly Lahuradewa and Senuwar, and Mahagara is later at 1800-1700 BC. While more data is needed this suggests a piecemeal process in which the adoption of winter crops was probably conditioned by local economic and social choices rather than by any widespread adaptive process. In this sense it would be similar to a 'food choice' model of adoption for social reasons which has been argued to apply to the adoption of wheat and barley in South India at roughly the same period[17]. This might therefore imply a much broader subcontinental context in which certain crops became culturally popularized.

The other part of the case for independent Gangetic origins comes from the biogeography of wild relatives of crops and from genetic studies on modern crops and their wild relatives. Northern India is the likely home of numerous crop species. Prominent amongst them, but poorly documented archaeologically, are various gourds (family cucurbitaceae), including, for example cucumbers, bitter gourds, snake gourds, ivy gourds and luffas[18]. As in many parts of the subcontinent wild forms of several small millets occur in this region, as does at least the mungbean amongst pulses in parts of the Himalayan foothills[19]. Most significant in terms of subsequent agricultural history, however, is rice. The case for rice domestication in India, however, has often been overlooked or denied. An assumption widespread in the literature, that all Asian rice derived from a single domestication, somewhere in the wild rice belt from eastern India across northern Indo-China or South China[20], has been based more on the presumption of single origins for crops in general, coupled with problematic archaeological inferences. This has been taken as an assumption by many archaeologists and historical linguistics dealing with South, East or Southeast Asian prehistory[21]. As I have summarized elsewhere this assumption is not supported by the genetic and taxonomic evidence, and is increasingly contradicted by archaeobotanical evidence[22].

Asian rice, despite being lumped under the name *Oryza sativa* (a convention since Linnaeus in the 1750s), is two distinct phylogenetic species, *indica* and *japonica*. This has long been suggested by plant breeding research, in which hybridization between these two cultivars is found to be difficult and imperfect, with the majority of crosses between *indica* and *japonica* cultivars being wholly or partly sterile[23]. There now is substantial evidence for genetic distinctions between *indica* and *japonica* from a range of data[24]. Most significant is genetic evidence from the chloroplast and nuclear DNA variants called SINEs. A sequence deletion in the chloropast DNA of *indica* cultivars links them with wild annual "*O. rufipogon*" (i.e. *O. nivara* in the taxonomy used here)[25]. Meanwhile, there are some seven SINEs that separate the *nivara-indica* group from the *rufipogon-japonica*[26] . Figure 1 shows the phylogenetic model produced by Cheng, *et al.*[27], in which the *japonica* cultivars form a very tight group in relation to the dispersed groupings of wild rufipogon types. The absence of any wild rufipogon on the base of the japonica sub-tree can be explained by climatic change which has eliminated wild rice from the Yangzi and adjacent parts of China where domestication is likely to have taken place under warmer climatic conditions. By contrast the grouping of *indica* is looser and more interspersed with wild *nivara*. In India climatically-induced extinction of wild populations would have been less pronounced than that in China as the high Himalayas blocked latitudinal shifts in wild rice distribution. Structure of the *indica-nivara* subtree might suggest that *indica* is composed of more than one domestication event from wild *nivara* populations, and thus a single origin in the Ganges may not be enough. On the basis of the modern geography of wild forms and cultivars at least one of these *indica* domestications in likely to have occurred in northern or eastern South Asia, while the *japonica* domestication can be placed in Southern China (quite plausibly including the Yangzi basin, when Early Holocene climatic conditions are taken into account). In Figure 2, I have attempted to summarize what we know about the distribution of modern wild rice populations, and the early regions of rice cultivation. This means that Lahuradewa, and other middle Gangetic sites, are geographically situated so as to be potential targets for research in *indica* rice domestication.

The Methodological challenge: Identifying domestication

What is missing from the archaeological evidence so far, both in China and India, is clear archaeobotanical evidence for a transition from foraging of wild rice, to cultivation, to the transformation of rice to a domesticated form, and for the change in subsistence away from a broader array of foraged resources to heavy dependence on rice. In this spectrum of changes pre-domestication cultivation is fundamental, marking a human behavioural change which will subsequently cause morphological and genetic changes in the plants[28]. Actually documenting the transition from foraging to cultivation and domestication remains a methodological

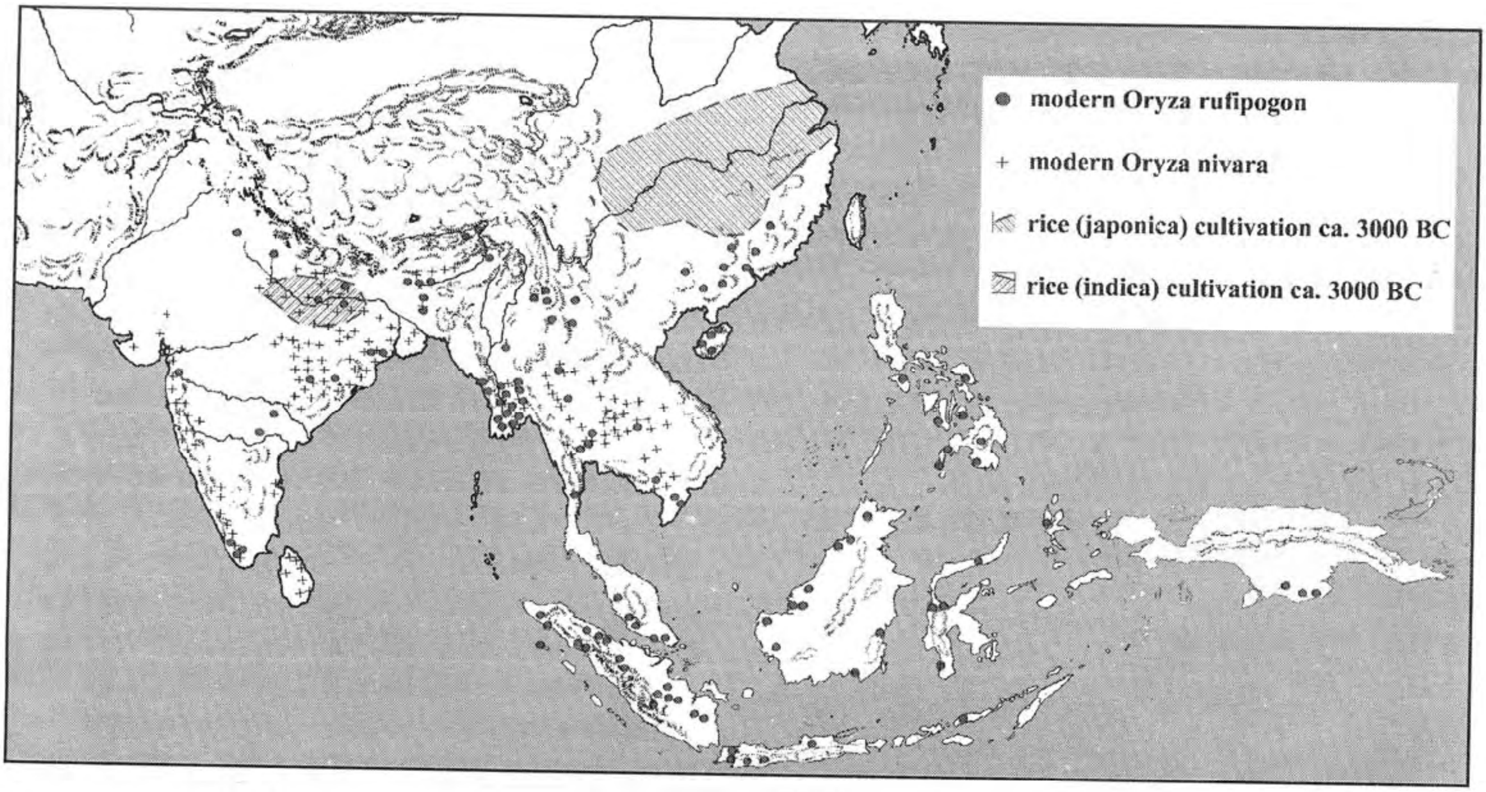

Fig. 2. A map of wild rice distribution and likely zones of domestication. The distribution of the two wild progenitors of rice is plotted after Vaughan (1994). Some of these populations may be feral, e.g. along west coast of India. The extent of rice cultivation ca. 3000 BC is indicated based on archaeological evidence (for China, after Yan 2002; for India, based on the author's current guess).

challenge. Claims for documenting the beginnings of domesticated rice are all theoretically flawed and potentially wrong, and further work is needed. The small sample size thus far available from Lahuradewa is still insufficient; and the detailed quantification of assemblages from other later sites in the region is needed, such as Senuwar, Mahagara, and Narhan, if we are to understand Lahuradewa in terms of a longer-term trajectory of change. There are three different aspects of rice domestication, or indeed that of any cereal, which should not be conflated but should be considered in turn: seed dispersal, even ripening and grain size increase.

The quintessential characteristic of domesticated grains crops in loss of natural seed dispersal[29]. This is achieved in rice by a toughening of the attachment of the spikelet base to the rachilla, and as shown by Thompson[30], this is accompanied by subtle changes in the cross section of the rachilla attachment scar. While in the wild rices mature spikelets should naturally separate and leave a clean scar on the spikelet base, while in domesticated rice this attachment is broken by human threshing and thus the scar should be roughened and uneven. The evolution of this toughened attachment is readily explained by natural selection and population genetics, as has been demonstrated in wild wheats[31]. Under the circumstances of cultivation and harvesting in which human harvesting is through cutting or uprooting, there is a bias towards collection of toughened mutants, which therefore enter the subsequent generation in larger numbers through sowing. Of importance is modeling the rate of change and the time that would be expected to fix the domestic type mutants in a population, and this depends on the strength of the selective force as well as the extent of continued gene flow from wild types into the seed of subsequent generations. Unlike wheat and barley which are almost exclusively self-pollinating, wild rice has been shown to have significant out-breeding on the order 40-60% of fertilized florets[32]. Thus by contrast to self-pollinating species in which, under strong selection from harvesting and sowing, 'domestication', the populational process of fixing the tough-rachis mutants, could happen in 20-30 years, strong selection in cross-pollinating rice should double this to ca. 50 years[33]. But crucial to this model is the selection pressure favouring the domestic type mutant, if this is greatly reduced to 10% or 5% then domestication slows greatly, even in self-pollinating species taking on the order 200-400 years. But with reduced selection pressure in a cross-pollinating species this slows to more than 1000 years. Thus it is crucial to consider how human activities set up this selection pressure: this includes harvesting by methods that favour tough mutants, saving a large proportion of the harvest for sowing the following year and sowing in areas without natural wild seeds of the species. If the same wild stand areas are resown, and the quantity of resown grain is equal to or less than the natural seed dispersal by the wild population there will be essentially no selection for domestication[34]. Other factors that might greatly reduce any selection for domesticated morphotypes are methods of harvesting, such as paddle and basket harvesting, widely used ethnographically for gathering wild grass seeds[35]. In addition, and probably quite significant, is that if wild cereals are harvested somewhat green, i.e. before most of the grains are mature, or if individual wild plants have a long period during which grains gradually come into maturity (which is the case with wild rice), grain loss to the harvester may be lessened but selection for the domesticated type will also be reduced.

Recovering the charred spikelet bases of rice may prove a challenge, but must be vigorously pursued in archaeobotanical sampling. Flotation samples that the author has studied from Late Neolithic Henan Province, China and from Medieval Mali in Africa, demonstrate that rice spikelet bases can be preserved in recognizable form charred and they tend to be just over 0.5mm (and occasionally slightly smaller). While our recent work at Mahagara has failed to recover any of these[36], the challenge remains to find sites in which they are preserved so that the evolution of the domesticate seed-dispersal syndrome can be studied directly.

Another contrast between domesticated and wild cereals raises even further complications, that might slow down the domestication process as well as complicate archaeological detection: even-ripening. One of the characteristics of most crops is that their flowering and production of seed is timed almost synchronously across the entire plant (and indeed population). In domesticated populations the though rachis allows for mature grains to be left on the plant while other spikelets catch up. This contrasts with wild relatives which tend have a much more extended period of seed production, which means that at any particular time a large proportion of the grains are immature or have already been shed. The implication for archaeobotanists is that ancient wild, and early cultivated, populations when harvested will produce a mixture of mature and immature grains. When seed dispersal is still by the natural shattering means, we might expect people to target more immature plants to decrease seed loss by shattering during the harvest process. This means we must take seriously the presence, perhaps even predominance, of the immature grain in early assemblages.

Immature grains will differ in the size and shape from their mature counterparts, and will complicate attempts to identify wild or domestic status from grain size and shape. The way the grains mature is that first they lengthen and fill-out the length of the husk and then gradually thicken in the final days of maturing[37] (Figure 3). This means that immature grains with have exaggerated length-to-width ratios. As conventional studies of modern material always focus on fully mature grains for comparing *indica* and *japonica* domesticates and wild forms, the simple extension of these to ancient materials is flawed. This

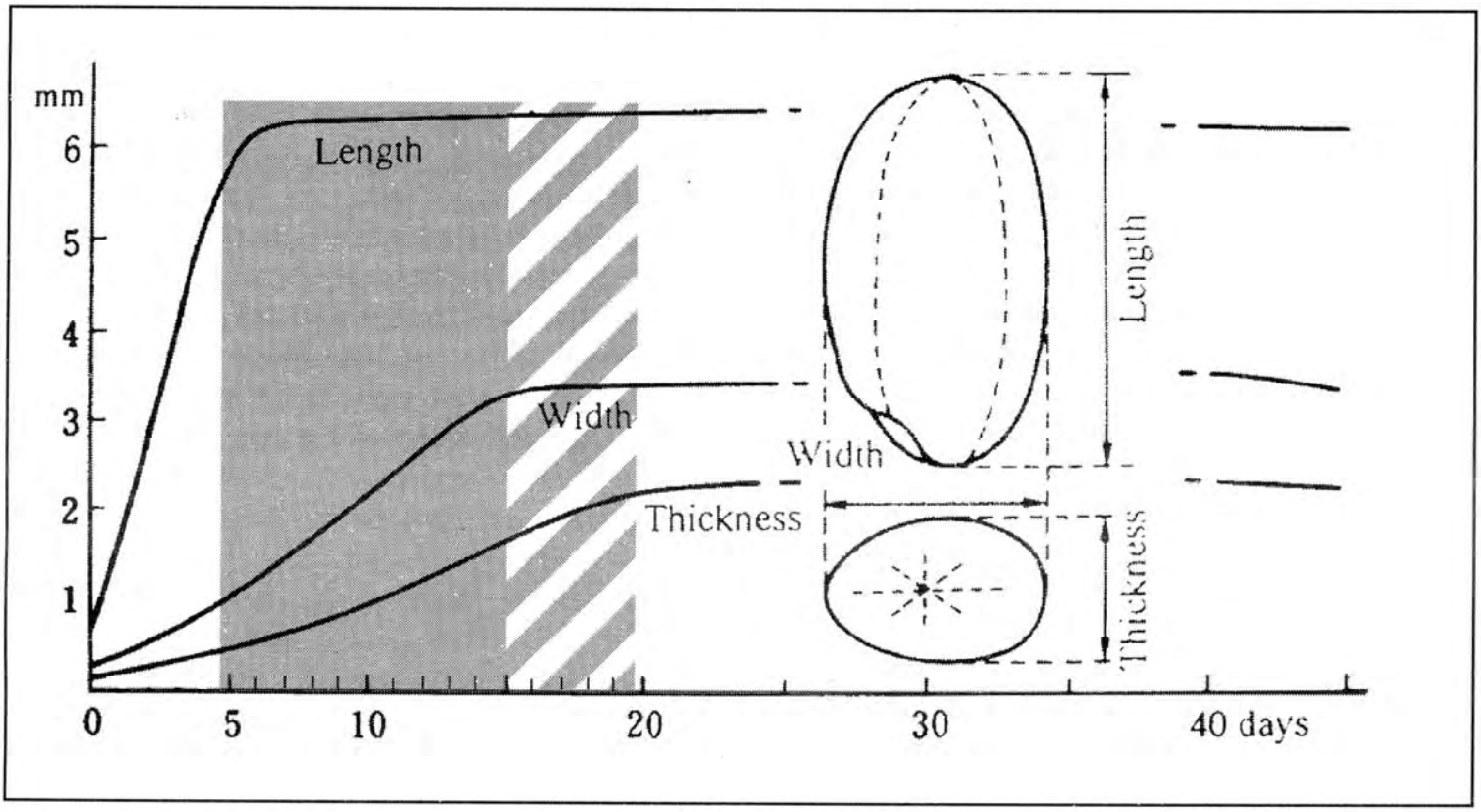

Fig. 3. Chart of *japonica* rice grain metrical development in terms of length, width and thickness measures (after Hoshikawa 1993), on which is shaded the period of grain immaturity in which grain proportions differ from those of standards based on the mature grain. Shown in solid grey is an approximate 10-day window during which immature grain proportions will be biased towards length, and thus closer to *indica* or *rufipogon,* rather than *japonica*. Similar complications must apply in the development of *indica* and *nivara* grains.

problem plagues Chinese archaeobotany, in which early rice assemblages, such as at the famous sites of Hemudu, Jiahu and Bashidang, are divided in proportions of *indica* and *japonica* varieties on the basis of grain length:width ratios[38]. The difficulty is highlighted by the fact that measured ancient rice assemblages in China do not match modern varieties nor wild forms but fall in an intermediate zone. They match neither the wild *rufipogon* rice of modern South China nor the *japonica* cultivars that were domesticated there, but often come closer, in ratio, to *indica* rices. Actual measurements, however, even allowing for probable size changes due to carbonization do not match *indica,* and many authors write of "ancient rice" varieties that are intermediate. This situation is readily explained if we consider these grains, or a large proportion of them to be immature, i.e. harvested green. This would also explain a hitherto mysterious phenomenon in which "*indica*" (based on L:W ratios) disappear during subsequent periods to be replaced entirely by *japonica,* and trend also identified in leaf phytolith shape[39]. Rather what is happening is that even ripening is setting in, selected as part of the domestication process, and the long thin immature grains disappear. Incidentally, if this change is taken as a measure of domestication, then full rice domestication in the Yangzi delta region of China may have taken place during the Fifth to Fourth Millennia BC, much later than often claimed! Earlier finds of rice, some of which are possibly Late Pleistocene, are in no case convincingly domesticated, and could relate to a very long tradition of efficient wild rice use by hunter-gatherers, to parallel the many millennia of wild cereal use in the Southwest Asia which preceded cultivation (see below). Similarly we should expect there to have been a long history of the use of wild rice by foragers in the Gangetic region. Such foragers are likely to have targeted crops somewhat green (with many immature grains) so as to minimize grain loss to shattering. Even amongst early cultivators distinguishing domesticated versus wild grains may prove difficult due to uneven ripening. Thus large populations of archaeological grains need to be measured and long-term metric trends over time documented. It is not prudent to simply divide grains into modern typological categories (such as domesticated, wild *rufipogon,* or *nivara)* on the basis of measurements on individual grains, as has often been done in archaeobotanical reports on Middle Ganges sites of various periods. Varying maturity level will obscure boundaries that appear clear in modern mature material (and even in modern samples there is overlap!), whereas larger diachronic studies of archaeological grain populations may reveal trends of change which can then be interpreted in terms of rice evolution and the evolution of human economies.

Other changes with domestication which are also important may be less apparent in archaeological materials, but nevertheless need to be taken into account in developing models of the domestication process. Another common change in the domestication of some plants is the loss of natural germination mechanisms (which often inhibit seed germination until a particular season). In rice, for example, domestic grains are ready to germinate within 2 months of ripening and harvesting, whereas wild rice requires some 6-8 months after maturation before they will germinate[40]. This differs from the situation in wild emmer wheat in which it is normally only half of the grains, one of each spikelet pair, that germinate in the first year[41]. This has implications for the processes of selection under early cultivation. In Southwest Asia (the Levant) sowing and harvesting favoured individual plants in which mutations allowed both grains in each spikelet to germinate when initially sown. By contrast, in rice we need to consider what human actions might have selected for the reduction in dormancy, and the extent to which early crops may have germinated unevenly, which might have further increased uneven ripening.

The basis of food production is a direct involvement of humans in the management of the lives and life cycles of certain plant and animal species, termed 'domesticated'. It is the management of these species, over hundreds of years, that led to the *evolutionary* changes of domestication. Thus a very real archaeological challenge is to identify the beginnings of cultivation amongst morphologically wild rice, and track the gradual biological changes this incurred. Theoretically this could be a longer stage than that for wheat and barley due to the cross-pollination which is common amongst wild rices, and much longer if we assume higher levels of uneven ripening in wild rice, which seems to be indicated by sources available to me at this time. In Southwest Asian archaeology, this challenge is now being met, and in the past 10 years evidence for pre-domestication cultivation has been recognized through the statistical composition of wild seed assemblages which document the inferred emergence of weed ecologies[42]. Future research in India needs to pursue similar evidence if we are to ever understand the processes of agricultural emergence in this region. More flotation, more seeds, and more quantification of their composition is needed, along side increased attention to the quantitative patterns of morphology and size in the crops themselves.

Alternative agricultural trajectories: some models and expectations

Four elements of the conventional 'Neolithic' need to be decoupled and considered separately. These include sedentary settlement, the production of pottery, plant cultivation (and subsequent domestication), and livestock herding. Lessons and contrasts can be drawn from what in known in Southwest Asia, Africa, East Asia, the Americas and perhaps other parts of India.

In Southwest Asia, sedentism and use of wild cereals both have greater antiquity than food production. Wheat and barley use by hunter-gatherers began in a fairly intensive way during the Kebaran period, at ca. 19,500 bp, as indicated by the archaeobotanical evidence for wild emmer and barley in substantial quantities from Ohalu II in Israel[43]. This means that use of the wild cereals preceded cultivation by ca. 8000 years and clear evidence for domestication by more than 10,000 years! This highlights the need to consider a potentially very long period of use of wild rice by Gangetic hunter-gatherers (to which the earliest levels at Lahuradewa might relate), even into pre-Lahuradewa times. It is also clear that in the Levant population became largely sedentary during the Natufian period (before 13,000 bp) based on a hunting and gathering economy[44]. The beginnings of agriculture then took place amongst some settled hunter-gatherers who began to rely more heavily upon and cultivate wild cereals, probably as a response to the suddenly arid conditions of the Younger Dryas climatic event[45], ca. 13500 bp. Evidence for cultivation of wild cereals (rye, einkorn and barley) is inferred for the Late Natufian and PPNA from sites such as Abu Hureyra, Jerf el Ahmar and Mureybit on the basis of the emergence of a distinctive arable weed flora alongside morphologically wild cereals[46]. Clear evidence for domesticated cereals emerged later, by the early Pre-Pottery Neolithic B, and domesticate sheep and goats were incorporated by the Middle Pre-Pottery Neolithic B. Ceramics did not begin to be produced until much later, ca. 6000 BC.

Africa shows a very different sequence of developments. There ceramics may have been first, then domestic animals and only much later plant cultivation and sedentism[47]. Evidence relating to wild plant gathering traditions that are probably ancestral to plant cultivation comes from a number of sites in the Sahara desert, 7000-4000 BC. During this early to mid Holocene era, rainfall was higher and much of the Sahara had savannah or sahelian vegetation, as well as scattered lakes and seasonal playas. Archaeobotanical evidence indicates widespread traditions of wild grain harvesting including a fairly diverse range of grass species. Sites in the western desert of Egypt (Nabta Playa, Dakleh Oasis, Farafra, Abu Ballas) all include evidence that wild sorghum was amongst the grasses utilized. Sites in Southwest Libya, in the Tadart Acacus (Uan Tabu, Uan Afuda, Uan Muhuggiag, Ti-n-Torha) indicate a range of wild grasses but without evidence for Sorghum use. Of interest from the Acacus is evidence for domesticated watermelons, probably used for oily seeds, by ca. 4000 BC. Similar grass-harvesting is suggested by identifiable impressions on ceramics of the Shaheinab Neolithic tradition in the Sudanese Middle Nile region from the 5th to 4th millennium BC. There is no evidence yet to tie these traditions of wild grass use to the beginnings of cultivation and subsequent domestication of these species. Indeed the earliest evidence for domesticated Sorghum yet found in Africa dates from the first half of the first millennium BC[48], although domesticated sorghum had certainly reached India no later than ca. 1800 BC in the Late Harappan time horizon[49]. What this indicates is the lack of archaeobotanical evidence from Africa between the early/mid-Holocene foraging phase in the Sahara and the beginnings of cultivation in the savannas further south. Nevertheless, what is clear, especially in West Africa is that ceramics and pastoralism spread southwards out of the Sahara and along its southern fringes local plants were brought under cultivation such as pearl millet (Hindi *bajra*)[50]. The earliest finds, of archaeological pearl millet, however, date to ca. 1900 BC (and it is perhaps around this time or slightly later that it had reached India!), come from sites that represent the emergence of more sedentary living. Thus the absence of earlier evidence is likely to be conditioned by poor site preservation during more mobile forms of settlement.

If we can take these two cases as examples for contrasting the Ganges we can see parallels and differences. As in Southwest Asia it appears that plant cultivation preceded the introduction of domesticated animals. Unlike Southwest Asia but similar to Africa ceramic production began early in the Ganges, as documented at Lahuradewa. But as in Africa, it remains possible that this was being produced by hunter-gatherers, amongst whom wild grasses (including wild rice) were important resources, together with fish and hunted game. This also raises a possible parallel with the long ceramic traditions of East Asia. The Jomon culture of Japan had pottery prior to evidence for clearly domesticated crops for at least 10,000 years[51], with even earlier pottery in the Russian Far East[52], and comparable dates in parts of South China[53]. In the tropical lowlands of South America pottery begins in some local traditions ca. 4000-3500 BC, amongst forager-fishers[54]. In Japan sedentism was certainly widespread by the middle Jomon village sites from ca. 3000 BC[55]. In this period, and certainly by the Late Jomon (after 2200 BC) cultivation of native barnyard millet (*Echinochloa crus-galli*) had begun in parts of Japan[56] but this appears to have been a fairly minor supplement to a diet still focused on wild tree nuts, including acorns. Similarly in Eastern North America, where domestic plants are evident after 2000 BC, the economy has been characterized as 'small scale food production'[57] in which the majority of the diet still comes from wild forest plant resources. This also warns against assuming the presence of rice, whether cultivated or wild, indicates dietary dependence. More work needs to be aimed at documenting the processes of dietary change and how they relate to the development of agriculture.

Towards explanation: push or pull

The Neolithic revolution also marks important changes in cultural tradition, social values and the use of material symbolism. Childe[58]: pointed towards important changes in religious systems and the use of fire to make permanent transformations of substance, as in the production of pottery, the first explicit human manipulation of a chemical transformation. The Neolithic may be a key horizon of change in the use of physical symbols as a means of communicating and remembering cultural information about tradition[59]. As discussed in general terms by the anthropologist Wilson[60], the house and village provide a powerful new model and means for reorganizing society and cosmology through which humans, and the places they lived, became "domesticated"[61]. Bradley[62], amongst others, has discussed the role of apparently domestic symbolism, including that from agricultural production, in the construction of ritual spaces, and memorial practices in the Neolithic of northwest Europe. In the context of Southwest Asia, discussion has highlighted how soils and clays became important substances for transforming social space and signifying social divisions and relations[63]. In the case of South India, we can see the by-products of penned cattle, namely dung, as potent symbols, when combined with practices of burning, and other unpreserved activities, at key spatial and seasonal junctures. In South India it was the cattle-herd and pen that provided a key set of symbols, as represented by the Southern Neolithic Ashmound sites[64]. And it is in the transformation of these symbols that we can see the transition from the Neolithic towards the more complex societies and social hierarchies that start in the South Indian megalithic and Early Historic periods. As evidence mounts from the Gangetic region, a consideration of how material culture functioned in new systems of symbolism and the new social structures related with food production and sedentism deserves special attention from researchers.

Different trajectories towards agricultural beginnings probably imply different explanations. The question of what caused mobile hunter-gatherers to settle down and become farmers remains contentious and challenging. In general we can divide explanations into two broad camps, those of food stress and food choice[65]. In food stress scenarios, which appears to apply in the case of Southwest Asia[66], there is an imbalance between growing populations and available food resources. This requires some sort of territorial circumscription, such as from neighbouring social groups, which encourages sedentism[67]. This situation may be created and exacerbated by climatic change, which appears to have occurred in Southwest Asia with the onset on the Younger Dryas dry period at the end of the Pleistocene. In particular, the Younger Dryas eliminated many plant foods and threatened the populations of wild cereals. Cultivation was a strategy to maintain wild cereals through human tending, with the eventual side effect of creating domesticates. A similar scenario could be considered for rice, but an understanding of how environmental changes may have squeezed the availability of wild food sources and wild rice is needed. During the course of the Holocene there have been numerous climate swings between wetter (and warmer) and drier (and cooler) conditions. These are becoming more clearly documented in South Asia through renewed work in the Thar Desert as well as in the Arabian sea[68]. Of particular relevance might be the major, rapid drying event at ca. 6200 BC, which was nearly half the severity of the Younger Dryas, or conditions nearly as dry in the period 5400-5000 BC. What is increasingly clear is that the drawn out drying towards modern conditions of the third millennium BC, especially marked at ca. 2200 BC, correlates with the emergence of more sedentary settlement, in South India as well as the Ganges[69]. Also of importance in northern India were the changes in the nature of the Ganges floodplain environment, to which work by I. B. Singh[70] is providing important insights. The impact of these hydrological changes on the distribution of wild rice and other plant resources needs to be modeled.

Other models for the origins of agriculture rely on social push factors, or 'food choice', such as models of competitive feasting or scheduled availability. Hayden[71] has long advocated the importance of competitive feasting for promoting the adoption of food production, as this allows the creation of larger surpluses that can be deployed strategically through feasting to gain prestige and social power. While attractive, this model is not yet supported from evidence for any case of pristine agricultural origins, although it may have played an important role in the secondary adoption of agriculture by hunter-gatherers in interaction with farmers. It implies the emergence of social complexity and hierarchy prior to the beginnings of agriculture. Another way of considering social motivations is the hypothesis of 'scheduled availability'[72], which has been argued to apply to Saharan Africa. In scheduled availability a plant species is needed for seasonal consumption within a cultural calendar, whether as a fall-back food or as an essential ingredient in certain recipes. In such cases, small scale cultivation at key localities will ensure the availability of this plant when and where it is required. Once cultivation has begun it may be extended to produce surpluses and produce staple food sources. One might consider early rice use in such a scenario, although other kinds of crops, which are more garden crops, might be more likely, such as the various native north Indian gourds.

Conclusion

Much remains to be done in research on the origins of agriculture in the Ganges basin. Important methodological hurdles need to be surpassed through more flotation, more sample analysis and more time consuming quantitative study. Such evidence needs to then be integrated into consideration of the broader trajectory from foraging to farming, sedentism and ceramics. Only once the trajectory (or trajectories) of cultivation and domestication is clarified will it become possible to assess different possible explanations of why ancient peoples of the Ganges Valley took to cultivation. In many environments hunting-and-gathering are time effective means of providing a healthy diet for relatively small human populations. Comparative studies indicate that most hunter-gatherers have more leisure time than farmers, are required to work less at subsistence and have better health[73], and it is therefore not surprising that archaeology suggests that there have been relatively few pristine transitions to agriculture worldwide. If I were to hazard a guess based on what we know today, I would guess that agriculture has been invented something like 16-20 times. This is more than most textbooks have assumed but still quite few in comparison to the number of regional hunter-gatherer traditions that can be recognized archaeologically. There is strong circumstantial evidence from biogeography, genetics and archaeology that one of these instances took place in the prehistory of the Ganges basin, but this remains to be clearly demonstrated and understood. Recent and future research at Lahuradewa is an important contribution to this understanding.

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Dr. Dorian Q. Fuller
Institute of Archaeology,
University College London,
31-34 Gordon Square,
London WC1H 0PY, U.K.
Email: d.fuller@ucl.ac.uk